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(54) **SYSTEM AND METHOD FOR WIRELESS ENVIRONMENTAL ZONE CONTROL**

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| *F24F 3/044* | (2006.01) |

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CPC *F24F 13/10* (2013.01); *F24F 3/044* (2013.01); *H02J 9/06* (2013.01); *F24F 2110/30* (2018.01); *F24F 2140/40* (2018.01); *G01D 5/142* (2013.01)

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CPC F24F 13/10; F24F 3/044; F24F 2110/30; F24F 2140/40
See application file for complete search history.

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(57) **ABSTRACT**

A system and method to control environmental parameters of predefined zones within a structure. An embodiment of the system uses damper assemblies that are entirely wireless as a result of energy capturing devices which convert air flow within the HVAC system ductwork into electrical current and a wireless control module that remove the need for hard-wiring for power or control. Still further, an embodiment of the system uses wireless components to monitor the environmental parameters of a structure's zones, process and communicate necessary zone adjustments, and actuate system components.

15 Claims, 12 Drawing Sheets
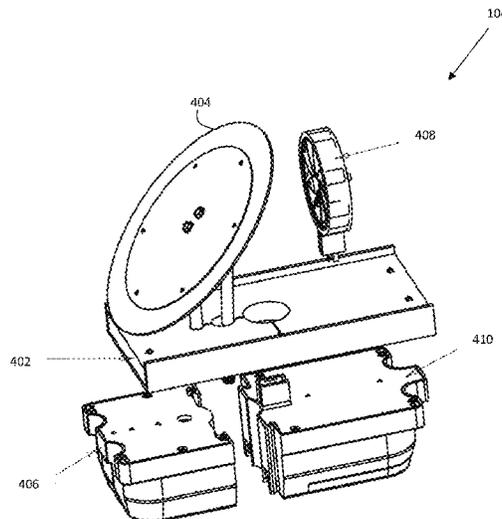
Related U.S. Application Data

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H02J 9/06	(2006.01)
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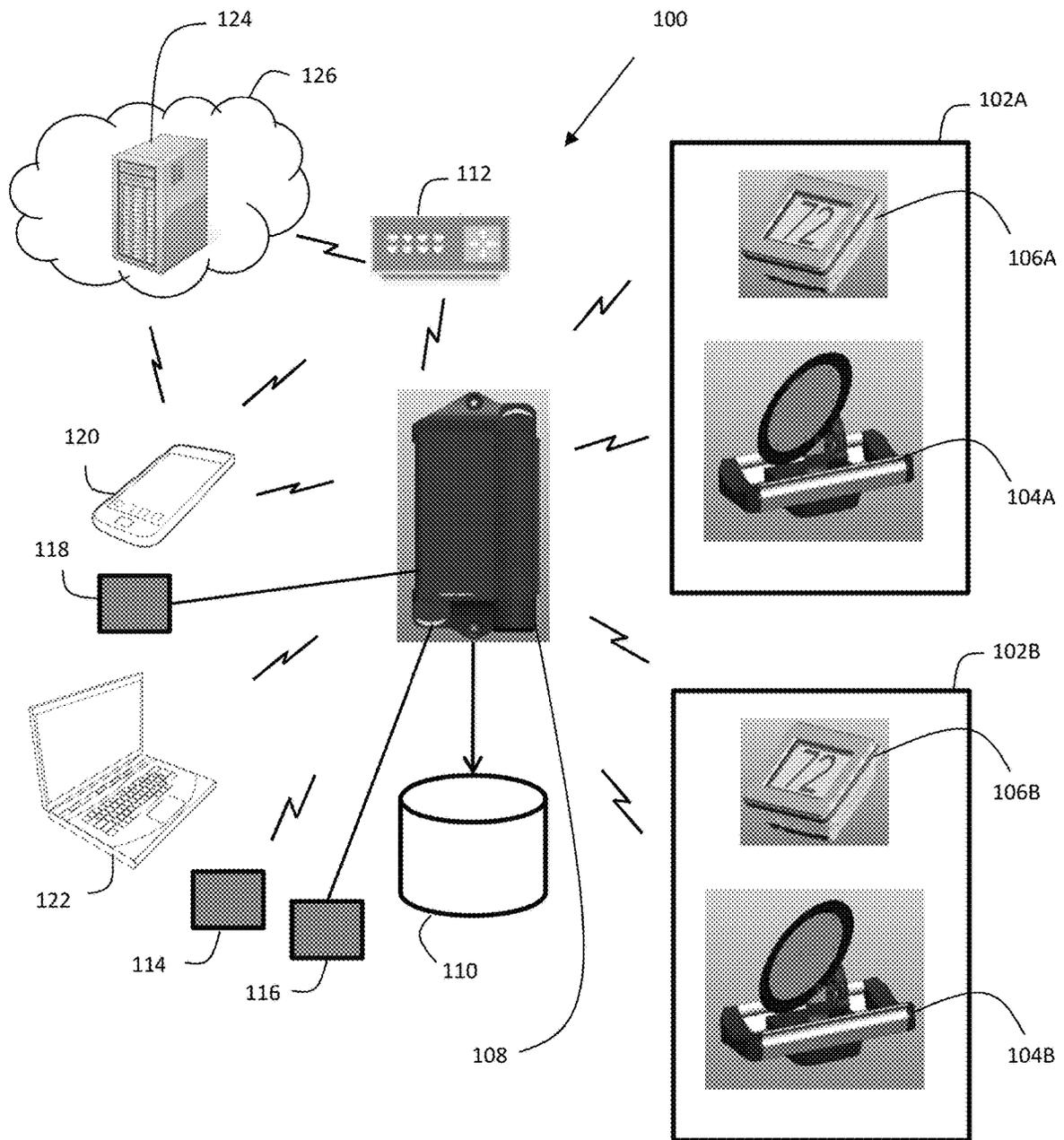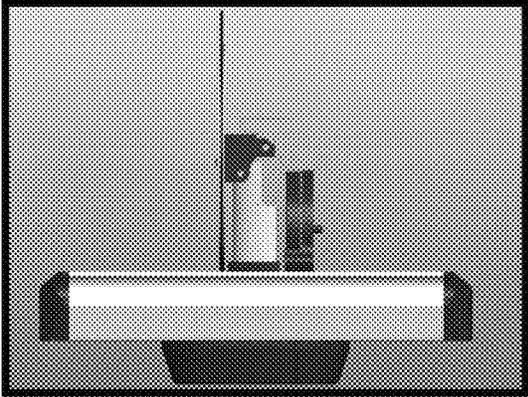Predictive Control for Energy Efficient Buildings with Thermal Storage. Ma, et al. Feb. 2012. http://sdb.cs.berkeley.edu/wiki/images/1/15/Ma12mpc.pdf.

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FIG. 1

202

FIG. 2A

204
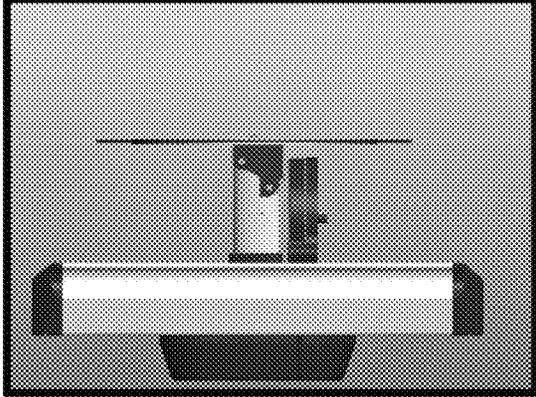
FIG. 2B
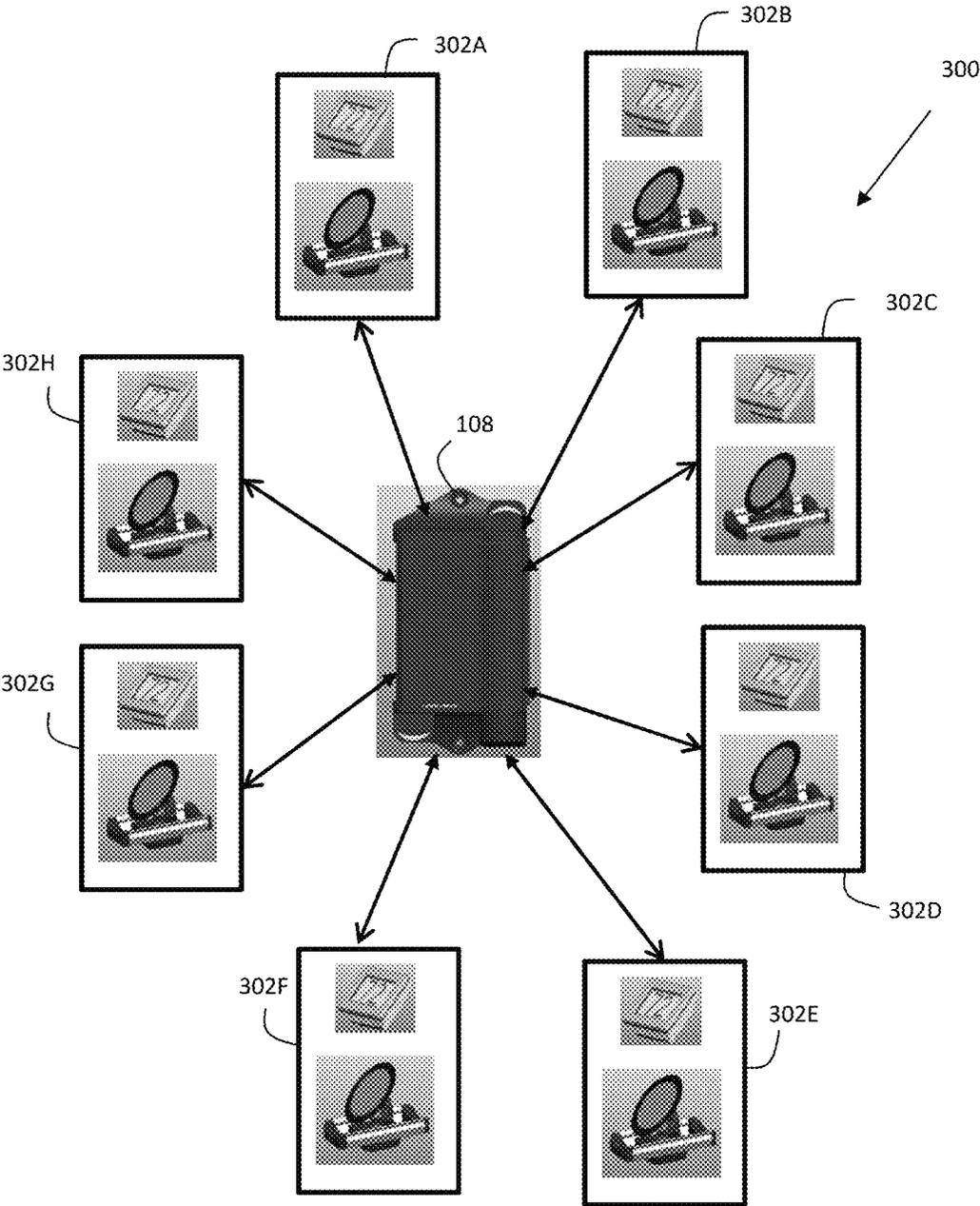
FIG. 3
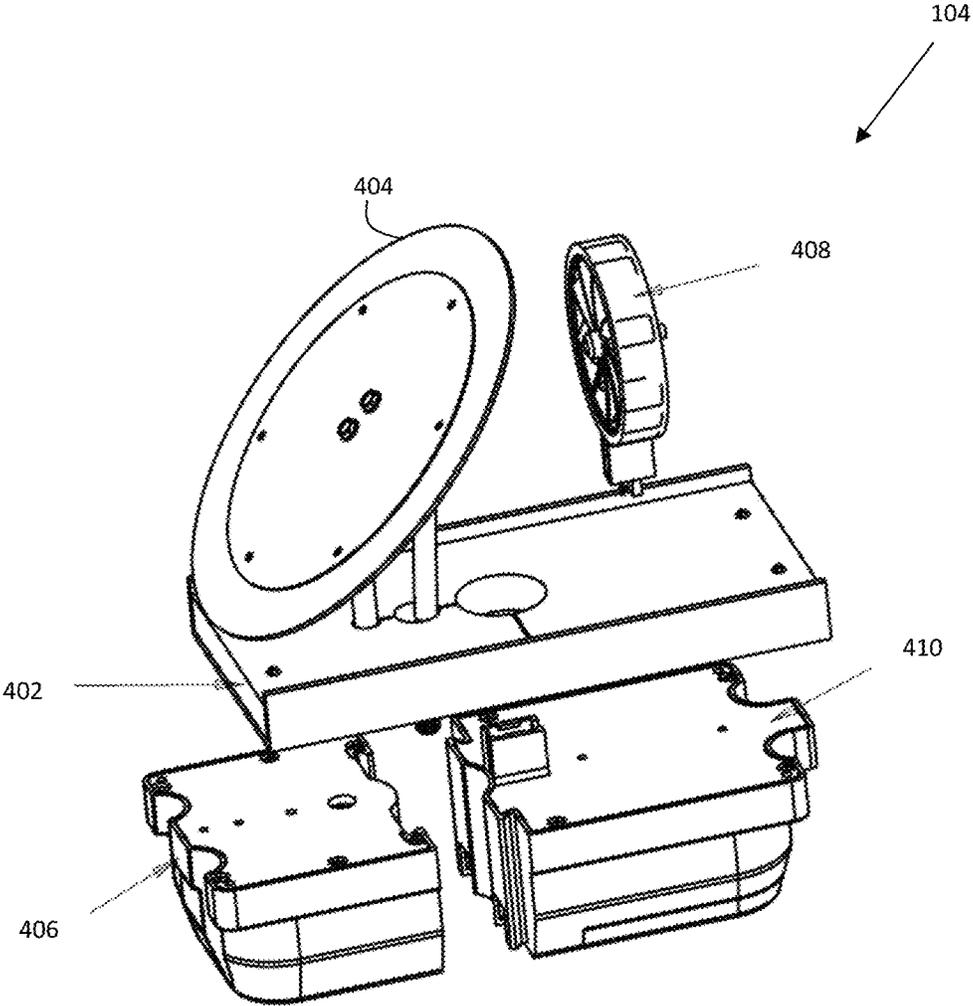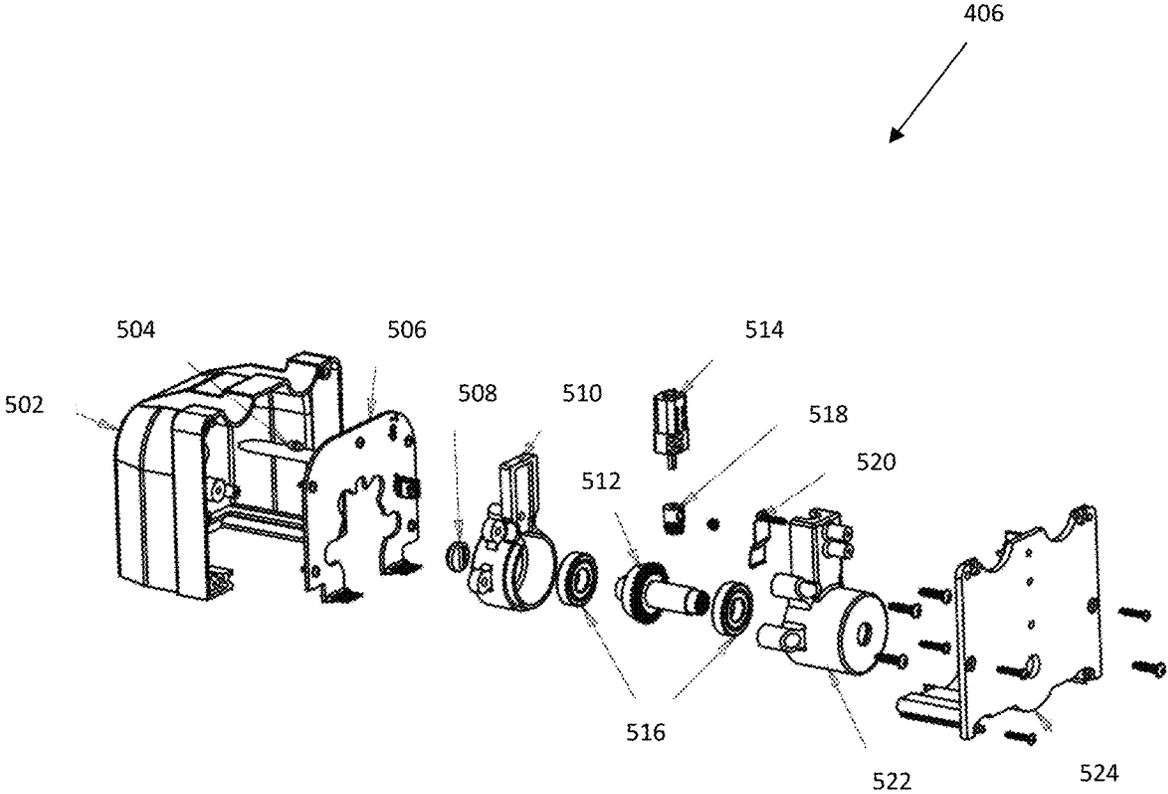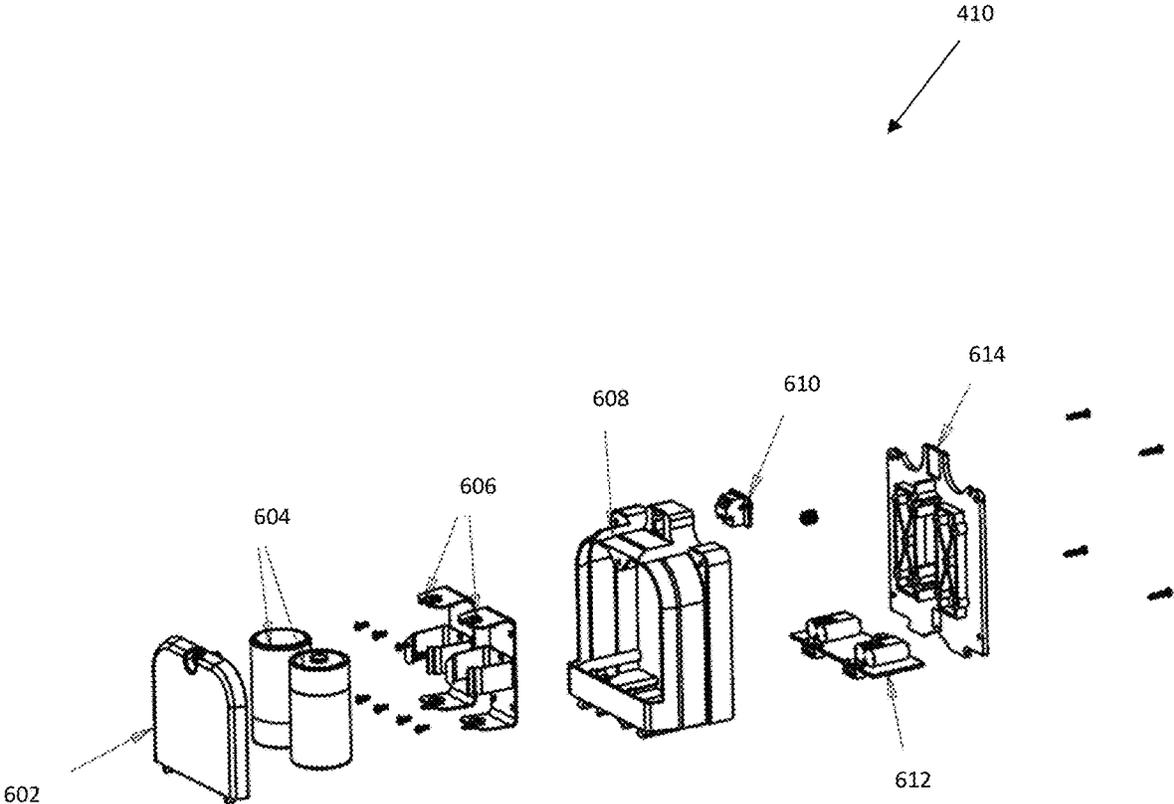
104

404

408

402

410

406

FIG. 4

406

504   506   514

502   508   510   518

512   520

516

522   524

FIG. 5

410

602

604

606

608

610

614

612

FIG. 6

FIG. 7

FIG. 8

FIG. 9

120

Sign-in Module 1002	Dashboard Module 1004	Zone Module 1006
Scheduling Module 1008	Messages Module 1010	Settings Module 1012

FIG. 10

122

Sign-in
Module
1102

Dashboard
Module
1104

Setup
Module
1106

Messages
Module
1108

FIG. 11

1200

1204

1202

1222

1208

1206

1210

1220

1218

1216

1214

FIG. 12
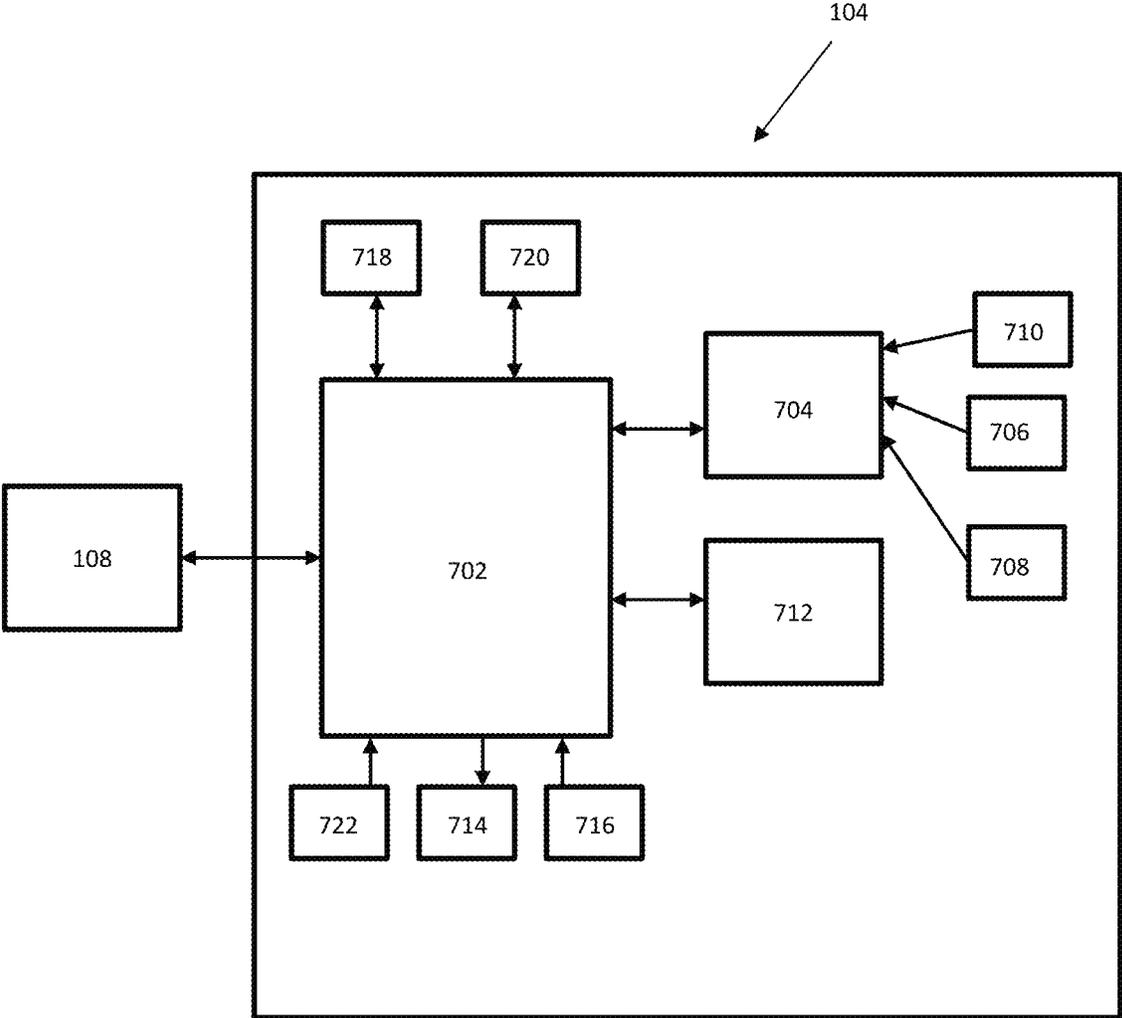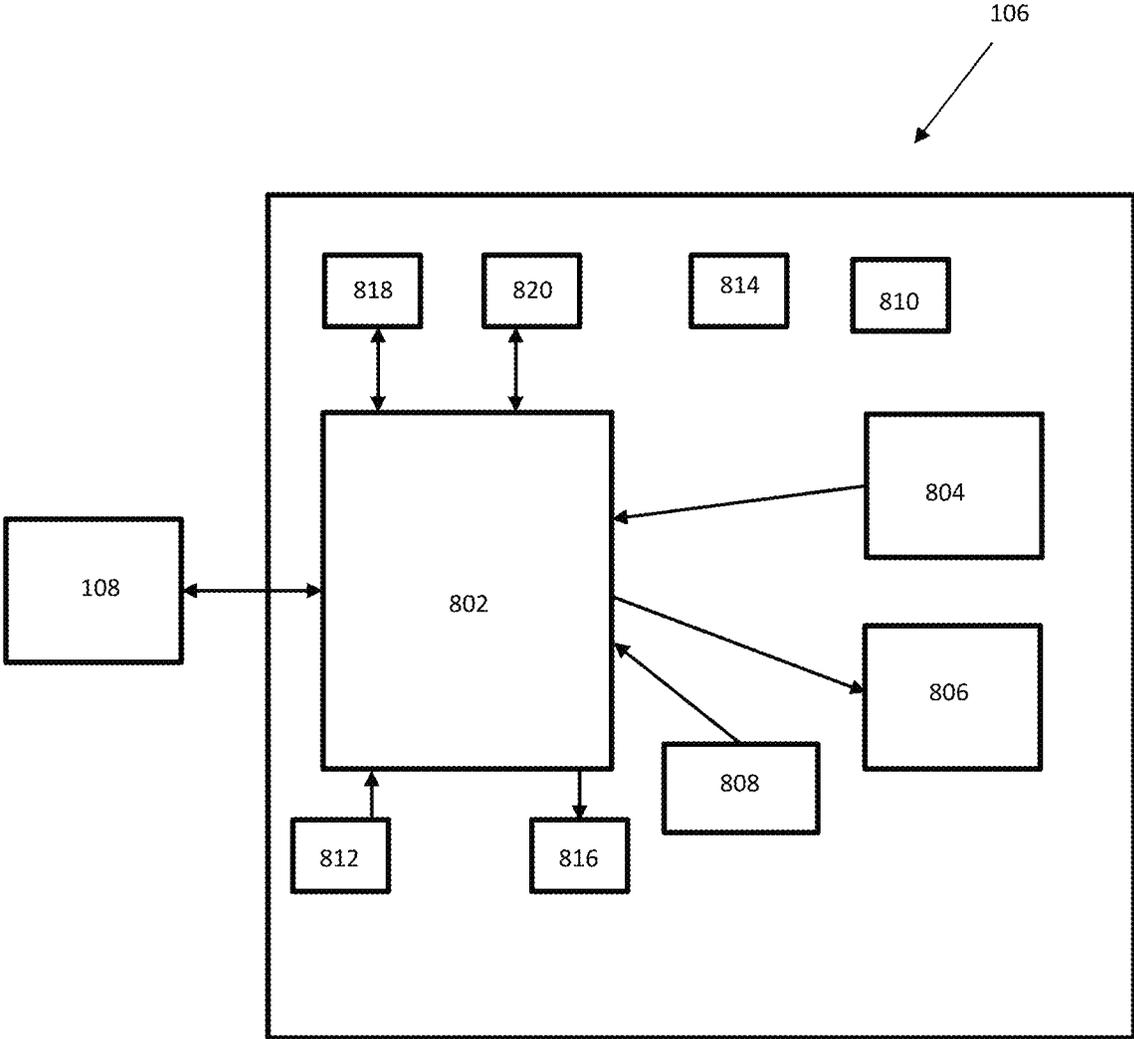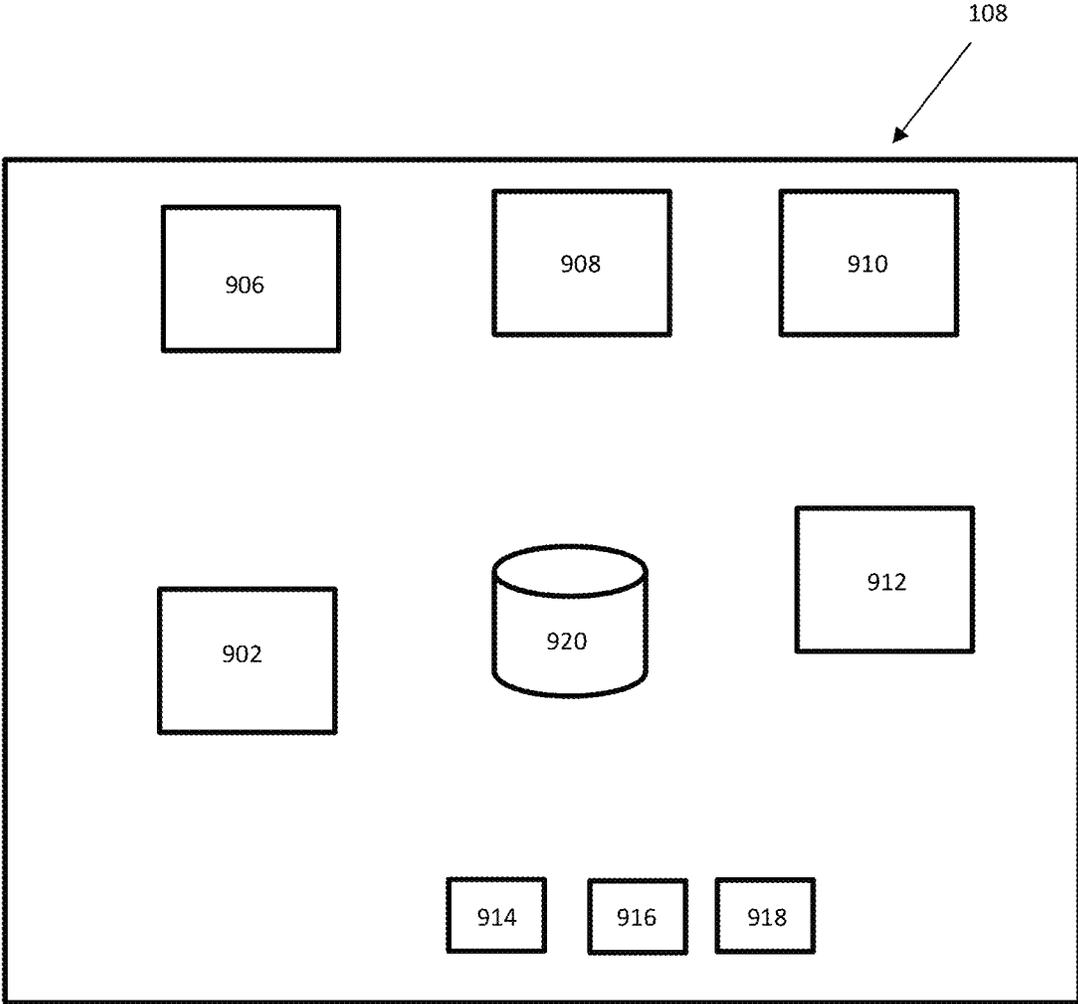
SYSTEM AND METHOD FOR WIRELESS ENVIRONMENTAL ZONE CONTROL

CROSS-REFERENCE TO RELATED APPLICATIONS

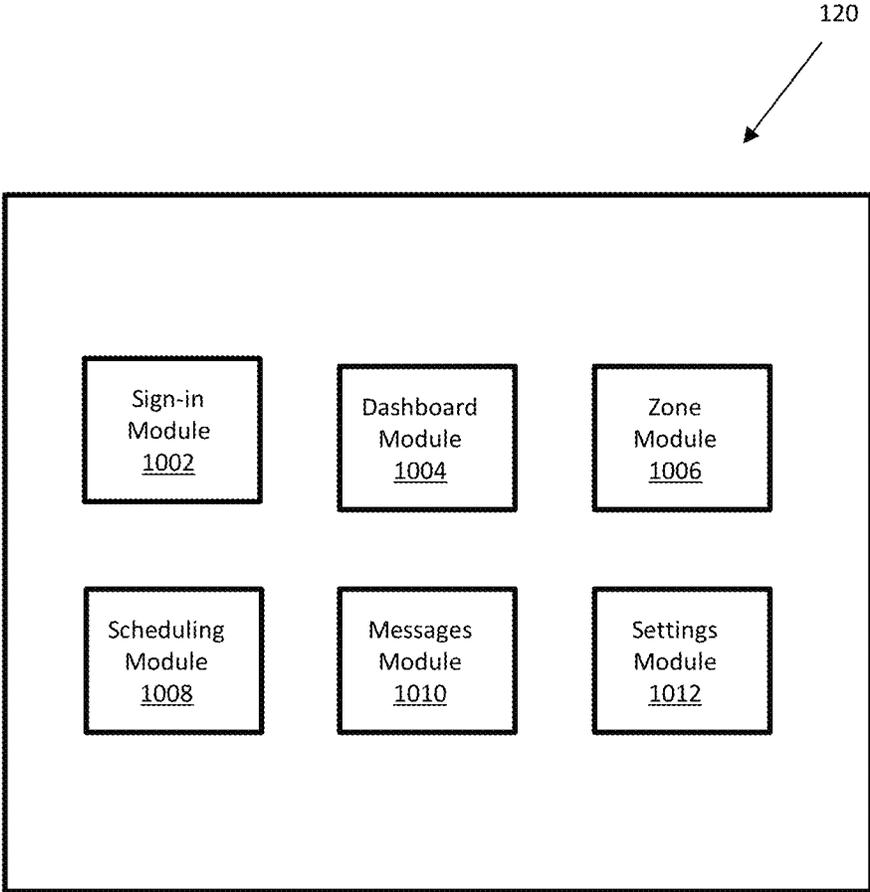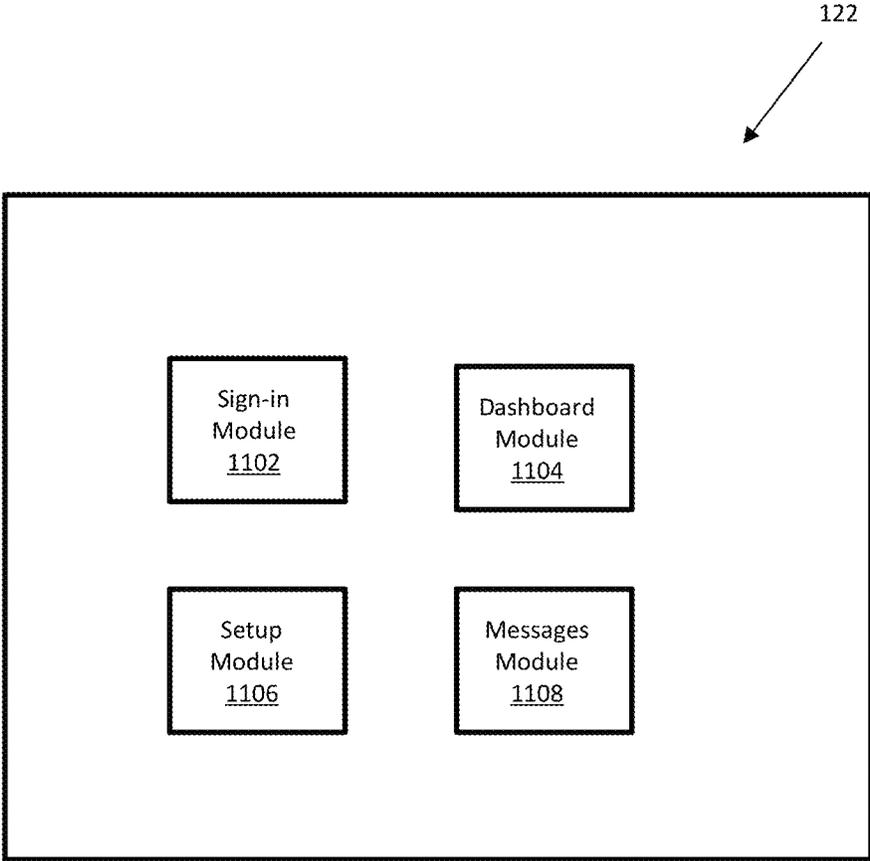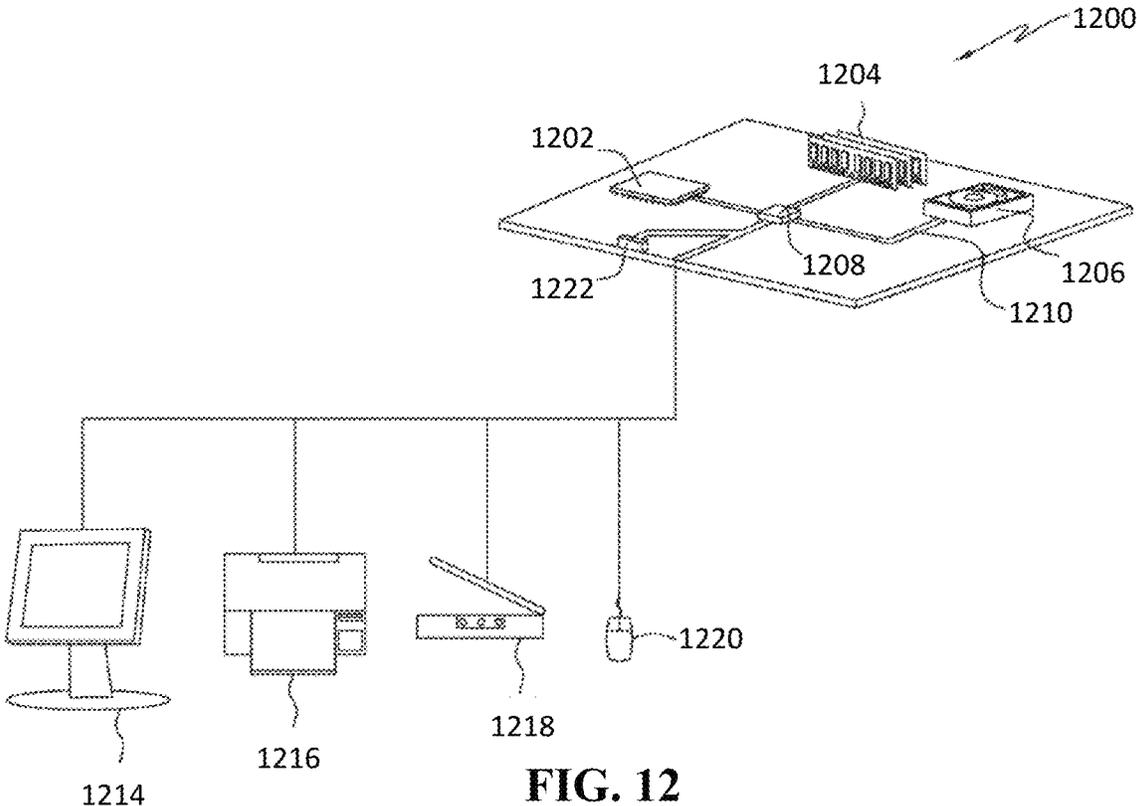This application is a continuation-in-part of U.S. patent application Ser. No. 14/881,920 filed Oct. 13, 2015, assigned U.S. Pat. No. 10,190,794, which claims priority to and the benefit of U.S. Provisional Patent Application No. 62/063,207 filed on Oct. 13, 2014, and U.S. Provisional Patent Application No. 62/107,789 filed on Jan. 26, 2015, all of which are incorporated herein in their entirety.

TECHNICAL FIELD

Certain embodiments of the present invention relate to HVAC zoning. More particularly, certain embodiments of the present invention relate to a system and method to control environmental parameters of predefined zones within an environment.

BACKGROUND

The cooling and heating of commercial buildings and residential homes is typically accomplished via forced air and forced hot or cooled water distribution systems. A furnace, heat pump, other fossil fuel furnace, and/or air conditioner are typically used to supply heated air or cooled air to areas of the building or home via ducts. Such distribution systems are often controlled by a single thermostat which is centrally located within the building or home. A person sets the thermostat to a particular temperature setting. When the temperature measured by the thermostat deviates a predefined amount from the set temperature, a furnace, heat pump, other fossil fuel furnace, or air conditioner is turned on to provide heated or cooled air or water to the various regions of the building or home via the duct work or water lines.

Even though the desired temperature may be achieved at the location of the thermostat, the resultant temperatures in the various other regions of the building or home may still deviate quite a bit from this desired temperature. Therefore, a single centrally located thermostat may not provide adequate temperature control for individual rooms and areas. In an attempt to address this problem, duct work and pipes throughout the building or home are fitted with manually adjustable registers, dampers, or valves which help to control the flow of air or water to the various regions.

A damper, which may generally be a valve or plate that stops or regulates the flow of air inside a duct, chimney, variable air volume box, air handler, or other air handling equipment, can utilize manual or automatic functions to shut off or restrict the flow of air into various rooms in order to regulate its temperature and climate. Manual dampers and valves are typically each adjusted to a single position and left in that state. Such an adjustment may be sufficient for a particular time of year, outside temperature level, and humidity level, but is likely not optimal for most other times of the year and other temperature and humidity levels. Furthermore, such an adjustment may only be suitable for a particular time of day due to the internal and external daily load variances that occur depending on, for example, the position of the sun, whether or not lights are on, and how many people are in a particular area. Moreover, it may be time consuming and difficult to manually re-adjust the dampers and valves for optimal comfort level. Dampers

actuated by electric motors or pneumatic components are a recent industry development which relieve homeowners of manual damper adjustments, but they may also require the installation of expensive and complex wiring, and/or pressurized air lines, to power sources and thermostats.

The complexity of damper flow control systems continues to increase as the industry has developed multi-zone control systems in an attempt to better control the environmental parameters in each room or region of a home or building, for example, by placing thermostats and/or sensors in each room or groups of rooms. A zone may be equipped with a temperature, humidity, motion, or other sensor in communication with a central thermostat or thermostat located in the zone. When the temperature falls outside of the defined acceptable range, the thermostat or sensor triggers actuation of the heating or cooling source, and/or movement of the dampers, until the zone once again achieves the desired temperature.

However, such systems are not entirely successful since a structure with multiple rooms and zones requires the installation of highly complex wiring systems, and/or pneumatic air lines, in order to provide power and control signals to the thermostats, sensors, and/or dampers. Specifically, the expense of the required wiring or air lines, its installation, and the utility bills associated with powering associated dampers, sensors, and thermostats can be cost prohibitive. Retrofit installation of wiring systems can be particularly difficult and expensive.

Moreover, known climate control systems are typically controlled by a centralized thermostat which is hardwired to a single location. This centralized thermostat, in turn, is hardwired to a power source and all dampers associated with the climate control system. Thus, a person desiring a change in temperature must physically move to the centralized thermostat in order to enter temperature control instructions.

In view of the foregoing discussion, it is apparent that there is a need for a more efficient way of controlling the distribution of air or water and environmental parameters for several zones in a building or home.

Further limitations and disadvantages of conventional, traditional, and proposed approaches will become apparent to one of skill in the art, through comparison of such systems and methods with the system and method as set forth in the remainder of the present application with reference to the drawings.

SUMMARY

In one example embodiment, a system to wirelessly control environmental parameters of a predefined zone is disclosed. The system includes a damper associated with the zone and configured to regulate the flow of air inside an air duct of the zone. The damper includes an optional wireless energy harvesting device adapted to capture energy in an HVAC conduit. The damper further includes an energy storage device adapted to store energy captured by the energy harvesting device. The damper assembly is configured to operate using energy generated by the energy harvesting device. The system further includes a temperature controller associated with the damper, configured to monitor the temperature in the zone, to receive as input a desired temperature for the zone, and to communicate data representative of the zone temperature and the desired temperature and to request service at the zone. The system further includes a control box in wireless communication with the damper assembly and the temperature controller, the control box configured to adjust the position of the damper to

regulate the flow of air inside the air duct of the zone based on the data representative of the zone temperature and the desired temperature received from the temperature controller.

In one example embodiment, a damper for an HVAC system is disclosed. The damper includes a rail assembly for providing support to the damper and for securing and sealing the damper on an air duct. The damper further includes a damper blade assembly configured to regulate the amount of air passing through an air duct. The damper further includes a damper module configured to control the orientation of the damper blade assembly. The damper further includes an optional scavenger assembly configured to harvest energy from air passing by the damper inside the air duct. The damper further includes a scavenger module configured to store energy harvested by the scavenger module.

In one example embodiment, a method for wirelessly controlling environmental parameters of a predefined zone is disclosed. The method includes the step of providing a control box, a wireless temperature controller associated with the zone, and a damper assembly associated with the zone, the damper including a wireless energy harvesting device, an energy storage device, and a module for actuating damper assembly operation. The method further includes the step of collecting data representative of the environmental parameters of the zone and data representative of desired temperature for the zone via the wireless temperature controller. The method further includes the step of wirelessly transmitting the collected data from the wireless temperature controller to the control box. The method further includes the step of processing the collected data to determine a corresponding control signal. The method further includes the step of wirelessly transmitting the control signal from the control box to the damper assembly. The method further includes the step of actuating damper assembly operation, in response to the control signal, using energy generated by the energy harvesting device.

The systems and methods described herein permit wireless control of HVAC systems via various wireless communications devices. The disclosure also provides for an HVAC system that utilizes "green energy" damper assemblies which convert air flow generated within routine operation into electrical power that powers various system components.

These and other advantages and novel features of the present disclosure, as well as details of illustrated embodiments thereof, will be more fully understood from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a schematic block diagram of an example embodiment of a system to wirelessly control environmental parameters of predefined zones within an environment.

FIG. **2A** illustrates an example damper of FIG. **1**.

FIG. **2B** illustrates an example damper of FIG. **1**.

FIG. **3** illustrates the example system of FIG. **1** configured in a star topology.

FIG. **4** illustrates an example damper of FIG. **1**.

FIG. **5** illustrates a portion of an example damper of FIG. **1**.

FIG. **6** illustrates a portion of an example damper of FIG. **1**.

FIG. **7** illustrates a block diagram of an example damper of FIG. **1**.

FIG. **8** illustrates a block diagram of an example temperature controller of FIG. **1**.

FIG. **9** illustrates a block diagram of and control box of FIG. **1**.

FIG. **10** illustrates a block diagram of an example homeowner computing device of FIG. **1**.

FIG. **11** illustrates a block diagram of an example administrator computing device of FIG. **1**.

FIG. **12** illustrates a schematic diagram of an example computer for implementing the example homeowner computing device and the administrator computing device of FIG. **1**.

DETAILED DESCRIPTION

Described herein is a customizable system for wirelessly controlling environmental parameters of predefined zones. The system combines temperature data with predefined zone parameters to determine how much air to deliver to a zone and when to deliver air to a zone. It should be appreciate that, although the system is described herein with respect to forced air systems, the system may also be applied to water distribution systems for heating and cooling. It should be appreciated that, although temperature measurements are referenced through the description, other suitable parameters such as humidity may also be measured, monitored, and/or controlled.

FIG. **1** illustrates a schematic block diagram of an example embodiment of a system **100** to wirelessly control environmental parameters of predefined zones **102A** and **102B** (hereinafter referred to as "zone" or "zones" **102**") within a first environment, in accordance with various aspects of the present disclosure. A zone **102** may comprise a portion of a large room, a separate room, or other connected areas in a house or other building, for example. A zone **102** may also be defined by a time of day. For example, a bedroom zone **102** may only be dynamically controlled at night when the bedroom is in use, and left closed off during the day when the bedroom is not in use. Similarly, an office building or restaurant not used at night may be closed off at certain hours of the night and dynamically controlled during the day. It should be appreciated that although the example system **100** is illustrated to wirelessly control environmental parameters of a first predefined zone **102A** and a second predefined zone **102B**, the example system **100** can be configured to wirelessly control any suitable number of zones **102**.

It should be appreciated that controlling temperatures in a configurable zone may be additionally advantageous in that static pressure buildup may be preventable. In particular, to prevent static buildup in a room, a zone may be configured in such a way as to prevent a certain group or groups of dampers from all being closed at the same time, which may otherwise result in static pressure buildup if they were all closed at the same time.

The system **100** further includes at least one wireless air damper **104A** and **104B** associated with each of the zones **102A** and **102B** respectively (hereinafter referred to as "damper" or "dampers" **104**). The damper **104** is configured to regulate the flow of air inside an air duct of an associated zone **102**.

In accordance with various embodiments of the present disclosure, the damper **104** may be a wireless damper that is powered by an energy capture device in combination with an associated rechargeable energy storage device (not shown). The damper **104** may be electromechanical, pneumatic, or

any other type of suitable damper. In some examples, damper 104 may articulate via a shape memory alloy.

The system 100 further includes temperature controllers 106A and 106B associated with each of the zones 102A and 102B respectively (hereinafter referred to as "temperature controller" or "temperature controllers" 106). The temperature controllers 106 serve as user interfaces capable of setting a temperature in a corresponding zone 102. Thus, a first temperature controller 106A may be configured to provide an interface for adjusting the temperature in a first zone 102A while a second temperature controller 106B may be configured to provide an interface for adjusting the temperature in a second zone 102B. In one example, temperature controllers 106 are portable and wireless and therefore may be moved according to user needs. For example, a user may move the temperature controller 106 to a couch while watching TV to enable the user to adjust the temperature in the zone 102 while watching TV. Thus, the temperature controller 106 may monitor, and in turn control, the temperature near the user in particular instead of a fix location in a room or zone. In another example, a user may move the temperature controller 106 to a fixed location within the zone 102 while away from the zone 102 to prevent unauthorized access. In one example, the temperature controller 106 may be configured to be mountable on a wall or otherwise secured to a fixed location within the zone 102.

The temperature controller 106 is configured to monitor the temperature in a zone and to display the temperature via an interface and also to receive input from a user about desired temperature. Desired input may be input, for example, via an interface at the temperature controller 106. It should be appreciated that the user may also input a desired temperature via an alternative interface such as a remote computing device. As mentioned below, the temperature controller 106 may also be configured to monitor humidity in a zone and display information indicative of the same, and also receive input from a user about a desired humidity (i.e., whether to run a humidification cycle or a dehumidification cycle). In even other embodiments, the temperature controller 106 may include other types of sensors to measure air quality in a zone and/or the presence of certain gases. For example, the temperature controller 106 may include a sensor configured to detect carbon monoxide, or a gas leak, or smoke, etc. In this manner, the system 100 may alert (e.g., an audible and/or visual alarm) the user to the dangerous condition (i.e., carbon monoxide and/or a gas leak) such that the user may take preventative action, such as exiting the zone/home, addressing the leak, opening windows, etc. In addition, the system 100 may monitor the building or one or more zones thereof for other parameters such as allergens, light, sound, etc. Moreover, the system 100 may be configured to take preventative action in such situations, for example, by alerting authorities and/or opening a vent to the outside environment to bring in outside air and/or clean, fresh air.

The temperature controller 106 is operatively connected to a control box 108 and configured to wirelessly communicate the zone temperature and desired temperature to the control box 108 and to request service at the zone 102. For example, zone service may include any of a heating call, a cooling call, a humidification call, a dehumidification call, and a fan-only call, in accordance with an embodiment of the present disclosure. The control box 108 is further operatively coupled to the damper 104 and configured to adjust the position of the damper 104 based on the received information from the temperature controller 106. For

example, the damper 104 may be adjusted a fully closed position 202, as illustrated in FIG. 2A, in order to block all or a majority of air from passing through inside a duct, or the damper 104 may be adjusted to a fully open position 204, as illustrated in FIG. 2B, in order to allow the maximum amount of air to pass through inside the duct.

Once a desired temperature in a zone associated with the temperature controller 106 is reached, the temperature controller 106 may communicate such information to the control box 108 so that the control box 108 may in turn adjust the damper 104 position accordingly if necessary. In one example, the control box 108 may determine that the system 100 may be experiencing a problem if a measured temperature at a temperature controller is not reaching a desired temperature and inform a homeowner or a contractor of the potential problem. For example, if a temperature controller 106 is broken or removed from an associated zone, it will not be able to accurately measure the temperature in its assigned zone. In such a scenario, the control box 108 may notify a homeowner of the problem and also either automatically close and open the damper 104 associated with the assigned zone where a problem is detected or rely on a wired backup temperature sensor to determine when to close the damper 104. In some examples, the system 100 may be configured to selectively condition one or more zones as needed while minimizing conditioning in other zones that don't need it, thereby providing energy savings and reducing hot and cold spots and temperature fluctuations between zones. For example, each of the zones may include a temperature sensors (e.g., in the temperature controller 106) and, based on temperature readings from the various zone, the control box 108 may identify which zones do and do not need heating, cooling, and/or air circulation. The control box 108 may then send instructions to the dampers 104 associated with the identified zones causing them to open or close (partially or fully) as needed to achieve the needed heating, cooling, and/or air flow. Thus, the control box 108 may control the dampers 104 to direct air flow to certain zones while minimizing (or even ceasing) air flow to other zones.

The control box 108, at the heart of the system 100, may be hardwired into a centralized location, or be of a portable wireless variety as described herein. In one example, the control box 108 may be configured as a micro access point or a Wi-Fi station, which may result in cost savings since a separate wireless access point 112 may not be required. In one example, the outer shell of the control box 108 is comprised of a suitable combination metal or other durable material to prevent damage to the inner components of the control box 108 as well as injection molded plastic to limit wireless signal attenuation. In one example, the control box 108 may be configured to be opened up in order to allow access to the inside of the control box 108 for maintenance and repair purposes.

Referring back to FIG. 1, the control box 108 is further communicatively coupled to one or more components associated with heating and cooling ("HVAC") equipment 110 such a heat pump, a furnace, a refrigeration evaporator, an electric resistance heater, or other suitable auxiliary components and equipment. The control box 108 is operationally connected to the HVAC equipment 110 via a relay connector or other suitable wired or wireless connector such that the control box 108 is configured to control the HVAC equipment 110. In some examples, the HVAC equipment 110 may be utilized to dehumidify. For example, if humidity falls below a user desired value, the heat from the HVAC equipment 110 may be turned on to dehumidify; whereas, if humidity rises above such user desired level, the cooling

from the HVAC equipment 110 may be utilized to extract moisture and thereby dehumidify. In other examples, a heating or cooling call is not needed to humidify or dehumidify. In these other examples, the HVAC equipment 110 may include a humidifier and/or dehumidifier and the user may simply initiate a dehumidifying and/or humidifying cycle on-demand. In these latter examples, the user may assess whether to initiate such on-demand humidity cycle based on humidity measurements. The humidity measurements may be taken from one or more locations in the home and then averaged to provide the user an average humidity level for the home such that they may control the humidity in the entire home; however, in some examples, zone specific humidity measurements may be provided to the user such that the user may control the humidity in one or more specific zones rather than the entire home. To measure humidity, one or more humidity sensors may be located throughout the home, for example, in one or more separate zones. In some examples, the temperature controllers 106 may be configured to measure humidity.

System 100 further may include a wireless outdoor temperature sensor (hereinafter referred to as "OA Sensor") 114 and a wireless leaving air temperature sensor (hereinafter referred to as "LAT") 116 in communication with the control box 108. The OA sensor 114 and LAT 116 provide temperature data to control box 108 for optimizing the closed loop transfer functions of the complete HVAC installation, as well for protecting the system 100 from overheating or freezing. The system 100 may further include a wired failsafe temperature sensor 118 in communication with the control box 108 and configured to provide the control box 108 with ambient indoor temperature data in the event of a wireless connectivity problem which would protect the system 100 from freezing. In another example, a return air temperature may be used as an approximation of the ambient indoor temperature. In one example, the OA sensor 114 and LAT 116 help provide protection against equipment back-up lockout. In one example, the OA sensor 114 and LAT 116 assist in duel fuel balancing and equipment staging. In some examples, the system 100 includes an economy mode or setting where outside air is brought into the building to cool (or heat) instead of utilizing the HVAC equipment 110 to drive temperature. For example, the building may have an outside vent configured to bring outside air into the building (or one or more zones thereof) when opened. The outside vent may include a damper such as damper 104 and, when running the system 100 in the economy mode, the OA sensor 114 may measure outside air temperature and the control box 108 may direct the damper 104 of the outside vent to open when the outdoor temperature is sufficient to cool or heat the building (or zones thereof) to the user desired temperature. Not only will this economy mode save energy, but it will also input fresh air in the building or one or more zones thereof. Thus, outdoor air measured by the OA sensor 114 may be utilized to control the indoor temperature of the building.

The system 100 further includes a homeowner computing device 120 configured to enable a user or homeowner to wirelessly access the control box 108 and to control the system 100, either directly while at home and within range of the control box 108, or remotely while away from home by connecting to the home wireless access point 112, via the Internet 126. The system 100 further includes an administrator computing device 122 configured to enable a contractor or other suitable systems administrator to wirelessly access the control box 108 and to perform initial setup and future troubleshooting and maintenance of system 100. In

one example, administrator computing device 122, is restricted to only accessing the control box 108 while at the home and connected to the system's 100 wireless network, which is distinct from a home's wireless network. This restricts the administrator's access and does not require granting of access to a home's wireless network to the administrator. In another example, the administrator computing device 122 may be granted access to the control box 108 remotely as well, either directly via a cellular network of control box 108 or via a secure connection through a home's router. In some examples, the system 100 is configured to integrate with and/or connect to various smart home systems and/or devices. For example, the system 100 may connect to hubs such as Google Home, Amazon Alexa, Amazon Echo, etc. In these examples, the user may control the system 100 with voice commands (and/or motion command such as sign language) received by the smart home systems or devices. Here, the user may tell the smart home system/device to raise or lower the temperature (or address another parameter in the building and/or zone), which in turn transmits the command to the control box 108 such that the action or adjustment is performed. However, in some embodiments, the system 100 may be configured to receive and respond to a user's voice commands without a smart home system and/or device. In some examples, the system 100 is configured to integrate with and/or connect to various home or building automation systems or devices, such as those of Crestron Electronics, Inc., Control4 Corporation, Savant Systems LLC, etc. For example, the system 100 may be connected to a voice activated remote control, such as the Savant "Pro Remote" or Amazon Alexa, for adjusting the indoor environment via voice command, and such devices may be used to send a signal to the system 100 to adjust temp in any zone upon receiving voice command from the user.

It should be appreciated that the homeowner computing device 120 and the administrator computing device 122 may be any suitable computing device such as a hard-wired desktop or laptop personal computer or a portable wireless electronic device—such as a mobile phone, laptop computer, and/or tablet computer—utilizing a software application (cloud, website, and/or device based) configured to monitor and respond to environmental factors received from the system 100. The homeowner computing device 120 and the administrator computing device 122 may consist of dedicated software and can operate on computers utilizing Windows™, Mac™, Linux™, or any other operating system and may use a private intranet or public website to access the network. The administrator computing device in particular 122 may be used by an installation worker during configuration and HVAC system setup, for example, while the homeowner computing device may provide users with information about zone environmental conditions and HVAC system status and permit users to request changes to environmental conditions in one or more zones in the structure through an interface system. As described below, the administrator computing device 122 may also be used by an energy supplier to control heating and cooling in one or more zones.

In some embodiments, other home or building automation devices—such as security, lighting, curtains, blinds, door bells, or other functions—may be controlled via the homeowner computing device 120 and the administrator computing device 122. In some examples where the building is outfitted with remote controlled valves and energy harvesting technologies, the system 100 may control other building parameters automatically and/or via user input. For example, hot water pipes and/or radiant heating in one or more zones may include Zigbee radio-controlled valves that the may be

controlled via the homeowner computing device **120** and the administrator computing device **122**. In such embodiments, the Zigbee radio-controlled valves may be hard wired to the building's power source or may instead include energy harvesting or renewable energy technology, or combinations thereof. Also, the system **100** may be integrated into a building's geo-thermal (if any) such that a user may monitor and/or control the geo-thermal system, for example, via the homeowner computing device **120** and the administrator computing device **122**.

System **100** further includes a remote computer data server **124** in the cloud, accessible via the Internet **126**. The computer data server **124** is configured to receive and store data from the control box **108**. For example, the computer data server **124** may store data relating to the HVAC usage of a homeowner. Such data may be beneficial for analyzing trends and making recommendations to the homeowner. In one example, the computer data server **124** may further be configured to perform such calculations and analysis based on received data and to provide recommendations or other suitable reports to the homeowner or to other authorized parties. In one example, only the homeowner computing device **120** may be configured to access the data stored by the computer data server **124** while in other examples, other suitable computing devices may be granted access to the stored data. In one example, the computer data server **124** may further be configured to be capable of communicating alerts or messages to the homeowner computing device **120**, if for example the system **100** is malfunctioning or with other suitable information. In some examples, the homeowner's energy supplier may be granted access to the computer data server **124** for inputting historical data, analyzing usage data, etc. In these example, the system **100** may be configured to provide energy conservation tips to the homeowner.

It should be appreciated that network communication between the components of system **100** can occur via analog or digital signals, with or without the use of a master or coordinator, and can create relationships that can include master/slave, peer-to-peer, or a combination of both. In addition, although specific components of system **100** have been described herein, it is to be understood that the number and arrangement of such system **100** components can be capped or scalable, that interoperability between components may or may not require bridging hardware, and that the network may be publicly or privately shared within a variable geometric spatial scope but may or may not communicate with other networks.

It should be further appreciated that the network topology for the system **100** communication control system may consist of various combinations of wired and/or wireless mediums. For wired connections, the control box **108** may transfer communications over, by way of non-limiting examples, twisted pair, coaxial, fiber optic, or ITU-T G.hn components, and may be interoperable with other networks via a gateway using BACnet or LonTalk protocols. For wireless connections, communications may occur, again by way of non-limiting example, via open or proprietary satellite, cellular, radio, infrared and/or other wireless personal area network protocols such as ZigBee™ Bluetooth™, Wi-Fi, Z-Wave™ or EnOcean™. The topological layout may be open (i.e., Mesh™ or Star™) as with the geographical scale (i.e., LAN, PAN, WAN). FIG. **3** illustrates one example in which the control box **108** is configured to control multiple zones **302A-H** by communicating with respective dampers and temperature controllers in each of the zones **302A-H** in a star topology. Such a start topology

may be beneficial in that the control box **108** may communicate directly with each of the zones **302A-H**. Thus, the control box **108** is having difficulty communicating with a first zone, such a malfunction will not interfere with the control box's **108** ability to communicate with the remaining zones. It should be understood that numerous combinations of wired and wireless system arrangements are contemplated to fall within the scope of this disclosure.

In one example, the control box **108** is configured to control a subset of dampers **104** based damper **104** associations with the multiple zones **302A-H**. As described herein, the control box **108** may also be configured to control other devices or systems (or a subset of the same) associated with the multiple zones **302A-H**, for example, security systems (and components thereof), fire alarm systems, home automation systems, lighting systems, curtain and/or blinds systems, door lock systems, door opening or closing actuator systems, garage door systems, hot water and/or radiant heating valve systems, geothermal systems, indoor and/or outdoor sprinkler systems, etc.

In various embodiments of the present disclosure, portions, or all of, the system **100** equipment are controlled via wireless communications. In one embodiment particularly suited for retrofitting an existing HVAC system with an at least partially wireless control configuration, the control box **108** is hard-wired into a centralized location but also operationally connected to home router and access point **112**. In another embodiment, the control box **108** may have integrated wireless communications components adapted to communicate wirelessly with other components of system **100** without requiring connection to or interference with a home wireless network.

FIG. **4** illustrates an example damper **104** in more detail. Damper **104** includes a rail assembly **402** for providing support to the damper **104** and for securing and sealing the damper on an air duct. The damper **104** further includes a damper blade assembly **404** configured to regulate the amount of air passing through an air duct. In particular, the damper blade assembly **404** prevents substantially all or a portion of air flowing inside an air duct to pass through, depending on the damper blade assembly **404** orientation. The damper **104** further includes a damper module **406** configured to control the orientation of the damper blade assembly **404**. In particular, the damper module **406** is configured to communicate with the control box **108** and to open and close the damper blade assembly **404** based on received instructions from the control box **108**.

In one example, the damper module **406** is able to determine the position of the damper blade assembly **404** based on the amount of power being drawn by a motor to open and close the damper blade assembly **404**. For example, a motor may require more energy to move the damper blade assembly **404** from a completely open state to a partially open state as compared to the amount of energy that may be required to move the damper blade assembly **404** from a partially open state to a closed state. Thus, the damper module **406** may translate the required energy into an approximation of the current state of the damper blade assembly **404**. In another example, the damper module **406** is able to determine the position of the damper blade assembly **404** based on data received from a Hall Effect sensor. For example, a Hall Effect sensor may be used to measure the magnetic field produced by a magnet in a drive shaft and, with this information, the position of the damper blade assembly **404** may be determined and adjustments to the position of the damper blade assembly **404** may be made,

for example, to open (fully or proportionally) or close (fully or proportionally) it to control the volume of air flow.

The damper 104 is further configured to generate and store its own power but also rely on a battery power source or an external hard wired source when needed. Thus, the damper 104 further includes an optional scavenger assembly 408 for harvesting energy from the air that passes by the damper 104 inside the air duct. In particular, the scavenger assembly 408 includes an impeller that rotates as air passes by. The rotation of the impeller in the scavenger assembly 408 is translated into energy and stored by the scavenger module 410. It should be appreciated that other suitable energy harvesting techniques may be used in place of a rotating impeller. It should further be appreciated that an energy harvesting may supplement energy requirements rather than providing all of required energy. In one example, the scavenger assembly 408 or the scavenger module 410 may be optional and removable.

In one example, the scavenger assembly 408 may consist of a wind-turbine type device that comprises one or more of a blade, rotor, shaft, pitch system, gear box, and generator to turn wind forces into wind-generated electrical power. In one example, the scavenger assembly 408 may have blades that are spoon shaped or airfoil propeller shaped. In one example, the scavenger assembly 408 may arrange turbine components on a vertical or horizontal axis in the form of upwind, downwind, shrouded, Savonius, flapping panel, or Darrieus or Giromill type devices. In one example, the scavenger assembly 408 may utilize gearless or reduction-geared gear assemblies. In one example, the scavenger assembly 408 may use electromagnetic induction. In other embodiments, the scavenger assembly 408 may use movement or pressure within system ductwork to capture energy for storage by the scavenger module 410. In still other embodiments, the scavenger module 410 may be recharged via the scavenger assembly 408 using thermally driven (thermoelectric), solar-powered (photovoltaic solar cells; concentrated solar power in the form of a Fresnel reflector, stirring dish, power tower, or other solar powering arrangements known in the art), radio scavenging, or rectenna/nantenna type harvesting technologies.

In the event that the scavenger module 410 does not have enough stored energy generated from the scavenger assembly 408, the scavenger module includes a battery backup which can be used to power the damper 104. The battery may be of various combinations of chemicals such as alkaline, lead-acid, nickel cadmium, nickel metal hydride, nickel iron, nickel hydrogen, nickel zinc, lithium ion, lithium ion polymers, lithium-air, lithium cobalt oxide, lithium iron phosphate, lithium sulfur, lithium titanate, sodium ion, thin film lithium, zinc bromide, vanadium redox, sodium-sulfur, molten salt, silver-oxide, or oxide semiconductors. In one example, the battery may be rechargeable.

In one example, the scavenger module 410 may be configured to operate the damper 104 in one of three modes depending on how much energy has been generated by the scavenger assembly 408 and stored and how much energy is currently being generated. For example, in a first mode, the scavenger module 410 may operate the damper 104 in a full energy scavenging mode, meaning the damper 104 is only being powered by energy being harvested by the scavenger assembly 408 or energy stored by the scavenger module 410 that was previously generated by the scavenger assembly 408. In this mode, the airspeed must meet a minimum predefined rate. For example, the airspeed may need to be at least 600 feet/minute for the scavenger module 410 to operate in the first mode. Air speed may be determined, by example, with a velocity sensor or a hand-held anemometer. In a second mode, the scavenger module 410 may operate the damper 104 in battery mode, meaning the damper 104 is powered entirely using the battery backup. This mode may be required if the air speed drops below a predefined threshold. For example, the scavenger module 410 may operate in battery mode when airspeed drops below 200 feet/minute. In a third mode, when the airspeed in the air duct is above the battery power mode threshold but below the full energy scavenging mode, the scavenger module 410 may operate the damper 104 in a hybrid mode using a combination of power from the battery backup and power generated by the scavenger assembly 408. In one example, the functionality of a damper 104 may be limited or restricted while operating in battery power mode or in hybrid mode. For example, while a damper 104 may function as a wireless router to facilitate wireless communication within system 100, the damper 104 may be restricted to an end device only when operating in battery power mode. It should be appreciated that the scavenger module 410 may be configured to operate in other suitable modes using various combinations of energy sources. For example, a fourth mode may include operating using an external hardwired energy source. In some examples, the damper 104 may function as a router or an end node regardless of how it is being powered, and in these examples the damper 104 may be configured to automatically detect whether it should operate as a router or an end node. For example, the damper 104 may be configured to automatically operate as a router when it is plugged into a power source (e.g., a 24 Volt power source). Once configured as a router, the damper 104 may operate in concert with the other damper devices allowing them to use the router feature to send and receive signals from the control box 108, and in some examples, the Zigbee chip in the dampers 104 does this automatically by "finding the easiest path" to send data to and from each other.

In one example, the impeller of the scavenger assembly 408 may function as an anemometer for determining actual speed of air passing through the air duct. The scavenger module 410 may be configured to store this information and communicate the information to the control box 108. In one example, the determined air speed may be used to select an operating power mode.

In one example, the energy generated by the scavenger assembly 408 may also provide power to the system control box 108, or other components of system 100. It should be appreciated that energy generated by the scavenger assembly 408 may also be used to power suitable components outside of the system 100. For example, the generated energy may be sued to power a UV light for bacteria cleansing.

It should be appreciated that the damper 104 may be of different types such as, for example, an electric damper driven by an electric motor that can be wirelessly activated or a pump that may be activated by wireless control signals to provide pneumatic pressure that opens and closes the damper 104.

It should be appreciated that the disclosure should not be limited to any particular damper assembly arrangement. Rather, any damper 104 that is capable of sealing or otherwise restricting air flow through an HVAC ductwork or air flow enclosure is intended to fall within the scope of the following arrangements. By way of non-limiting examples, mechanical power and transmission for damper operations may use solenoids and an air piston, bladder, diaphragm, or electrical motor with a gear box, for example. Linkage for

mechanical transmissions may also consist of belts and pulleys, an axle, or a linear actuator. It should be further appreciated that the impeller of the scavenger assembly **408** may be of any shape chosen by a person of sound engineering judgment, including but not limited to round, oval, triangular, rectangular, pentagonal, or hexagonal. The shape of the blade may be accomplished by foldable or expandable movement.

In a preferred embodiment, the damper **104** is of a wireless configuration, in that it does not require conventional wiring to the structure's central electrical system and does not need to be hardwired into control box **108** in order to receive control communications.

In other embodiments of the invention, the damper module **406** may also be adapted to receive and/or process wireless control signals forwarded from the temperature controller **102** or the control box **108**. Control signals received by the damper module **406** may prompt a request for transmission of power contained in the scavenger module **410** that is sufficient to actuate the damper blade assembly **404** to open or close, to varying degrees, depending on the amount of air flow required to bring a zone within desired environmental temperature or humidity ranges. The damper module **406** may optionally terminate actuation of the damper blade assembly **404** when control signals received indicate desired environmental conditions have been achieved.

It should be appreciated that an existing HVAC system may be retrofitted for wireless control of zone heating and cooling using the system **100** described herein. In particular, the damper **104** may be adapted to be retrofitted into existing ductwork. It should be further appreciated that in some instances, installation of the damper **104** may require portions of the ductwork to be removed while in other embodiments, the damper **104** may be inserted through an unmodified ductwork and/or register boot. In some examples, the damper **104** may be may be inserted below or behind the register and, in these examples, the scavenger assembly **408** thereof (if any) may be similarly positioned relative to the register such that it is able to harvest energy from air passing through the duct work even when the register is closed. In some examples, the damper **104** may be integrated into the register unit, such that the register includes the damper and (optionally) the scavenger assembly **408**. In this manner, installation of the damper **104** is facilitated as it is installed with the register and without needing a separate installation step. The system **100** may also be suitable for new construction homes and buildings where the HVAC system may be designed to work with the system **100**.

FIG. **5** illustrates an expanded view of a damper module **406**. The damper module **406** includes a housing **502** inside which is disposed a damper printed circuit board **506** coupled to an LED indicator light pipe **504**. An adjustment knob **508** for assisting with installation and removal is coupled to an actuator nut **512**. The adjustment knob **508** may further be used for manual actuation in the event of a malfunction. Gearbox bearings **516** are disposed on either side of the actuator nut **512**. The drive motor **514**, coupled to the drive gear **518** which is operationally coupled with the actuator nut **512**, drives movement in the damper blade assembly **404**. An actuator mount **510**, actuator retainer **522**, and motor retention spring **520** provides support for the actuator motor **514** inside the housing **502** which is sealed by the damper module cap **524**. The motor retention spring **520** also acts as a spring-back when adjustment knob **508** is used during manual actuation.

FIG. **6** illustrates an expanded view of a scavenger module **410**. The scavenger module **410** includes a housing **608** to support a battery cell cradle **606**. A battery cover **602** secures one or more batteries **604** in the battery cradle **606**. The scavenger module **410** further includes a power connector **610**. The scavenger module **410** further includes a printed circuit board **612** for facilitating operation of the scavenger module **410**. For example, the printed circuit board **612** is configured to receive and store energy harvested from the impeller. The printed circuit board **612** is also configured to manage distribution of power. The printed circuit board **612** is secured to the housing **608** by a cap **614**. It should be appreciated that, although the scavenger module **404** is illustrated to include a single printed circuit board **612**, the functionality of the printed circuit board **612** may also be separated into two or more printed circuit boards.

FIG. **7** is a block diagram of the example damper **104** of FIG. **1**. The damper **104** includes a microcontroller **702** for facilitating communication and control of the damper **104** with control box **108**. In one example, the microcontroller **702** is an 88MZ1000 manufactured by Marvel. However, it should be appreciated that any suitable microcontroller can be used. A damper actuator **712** receives control signals from the microcontroller **702** instructing the damper actuator **712** when to open and close the damper in order to allow air to pass by or to block air. In one example, the microcontroller **702** also may receive suitable data from the damper actuator **712**. For example, a sensor coupled to the damper actuator **712** may measure torque generated by passing air and communicate the measured data to the microcontroller **702**.

In one example, the microcontroller **702** may be configured to detect current spikes while the damper is opening or closing to prevent the damper from actuating when current spikes are detected.

The damper **104** may be configured to determine the position of the damper blade of damper actuator **712** and/or to control operation of the damper actuator **712** via a Hall Effect sensor. For example, one or more Hall Effect sensors may be coupled to the damper actuator **712** that moves the damper blade and be configured to communicate with the microcontroller **702**. Here, the microcontroller **702** receives feedback signals from the Hall Effect sensors, where such feedback is indicative or representative of the position of the damper blade that is coupled to the damper actuator **712**. Using this feedback, the microcontroller **702** may determine a position or orientation of the damper blade (of the damper actuator **712**), for example, by correlating the feedback information to an actual damper position via a look up table or mathematical relationship or the like. The microcontroller **702** may also be configured to control operation of the damper actuator **712** via the sensed position of the damper blade. For example, the microcontroller **702** may determine the speed, distance, and/or direction at which the damper actuator **712** drives the damper blade via data received from the Hall Effect sensors.

A power management module **704** manages the collection and distribution of power. For example, the power management module **704** is configured to receive power from an energy harvesting device **708** as well as from a rechargeable battery **710**. The power management module **704** also distributes power based on either the harvested energy or energy produced by the rechargeable battery to the controller and to the damper actuator **712**. In one example, the power management module **704** may further be coupled to and receive power from an AC power supply **710**.

The damper **104** includes a pushbutton **722** to enable a contractor or administrator to initiate a communication with

the control box 108 that will help identify the damper 104 for configuration purposes. The damper 104 also includes an LED indicator 714 that is configured to blink a corresponding zone color which can further assist a contractor or administrator in configuring the system 100 and setting up zones. In one example, the LED indicator 714 may keep blinking for a predefined time period such as 5 minutes to give the contractor sufficient time to identify the damper 104. In another example, the LED indicator 714 may keep blinking until the pushbutton 712 is again pushed. In one example, a buzzer 716 may provide a contractor with an audible notification which may further assist with identifying the damper 104 during configuration. It should be appreciated that either an audible or a visual notification may be used as needed, or a combination of both. In addition to assisting with configuration, the push button 722, the LED indicator 714, and the buzzer 716 may further assist the contractor when troubleshooting the system 100.

In one example, the damper 104 may further include one or more connectors for coupling to the microcontroller 702 for maintenance, debugging, configuration, and so on. In one example, the damper 104 includes a Joint Test Action Group ("JTAG") connector 718 and a Universal Asynchronous Receiver/Transmitter ("UART") connector 720. In one example, the damper 104 may further include an encoder for converting signals into digital form.

FIG. 8 is a block diagram of an example temperature controller 106 of FIG. 1. The temperature controller 106 includes a microcontroller 802 for facilitating communication and control of the temperature controller 106 with control box 108. In one example, the microcontroller 802 is an 88MZ1000 manufactured by Marvel. However, it should be appreciated that any suitable microcontroller can be used. The microcontroller 802 includes a wireless onboard antenna to communicate temperature and humidity data to the control box 108. The microcontroller 802 is further configured to communicate the temperature and humidity information to display 806.

The display 806 is configured to communicate data to a user. For example, the display 806 communicates or displays, in addition to temperature and humidity information, battery level, a temperature set point as desired by a user, a "heating" icon to indicate a heating mode, a "cooling" icon to indicate a cooling mode, and a "fan" icon to indicate a fan mode. In one example, the display 806 is further configured to display an icon or text indicating that a user action is required via the homeowner computing device 120. In one example, the display 806 is further configured to display an energy saving icon, indicating that due to an energy saving plan, a requested set point is not available.

In one example, the temperature controller 106 further includes one or more push buttons for enabling a user to provide input and set a temperature. It should be appreciated that such push buttons may also be provided via the display 806 using a touch screen interface. In one example, the display 806 may be further configured to display a current zone name.

The temperature controller 106 further includes a battery power supply 810 for powering the microcontroller 802. The temperature controller 106 further includes a sensor 808 configured to detect the presence of a person nearby and communicate the information to the microcontroller 802. In one example, the microcontroller 802 is configured to maintain the temperature controller 106 in a sleep mode to conserve the battery power supply 810 until a person is detected nearby, indicating that the person may wish to interact with the temperature controller 106. At that point,

the microcontroller 802 "wakes up" the temperature controller 106 and turns on the display 806 in preparation for interaction with the person. In another example, the microcontroller 802 is configured to maintain the display 806 in an active or on state while no person is detected nearby, displaying current room temperature. The microcontroller 802 may be further configured to change the display 806 to communicate a "set temperature screen" when a person is detected as being nearby.

The temperature controller 106 further includes a pushbutton 812 to enable a contractor or administrator to initiate a communication from the temperature controller 106 that will help identify the temperature controller 106 for configuration purposes. In one example, a buzzer 816 may provide a contractor with an audible notification which may further assist with identifying the temperature controller 106 during configuration. In addition to assisting with configuration, the push button 812 and the buzzer 816 may further assist the contractor when troubleshooting the system 100.

The temperature controller 106 further includes one or more connectors for coupling to the microcontroller 802 for maintenance, debugging, configuration, and so on. In one example, the temperature controller 106 includes a Joint Test Action Group ("JTAG") connector 818 and a Universal Asynchronous Receiver/Transmitter ("UART") connector 820.

The temperature controller 106 further includes a "WiFi join" pushbutton 814 that enables the administrator computing device 122 to connect to the control box 108 and enter a router password.

In another example, the temperature controller 106 is configured as a sensor without any user input or user output/readout capabilities. For example, the temperature controller 106 may be configured to measure one or more parameters, such as temperature, humidity, presence of a gases such as carbon monoxide, light, allergens such as pollen, smoke, etc. to maintain the building or zones thereof at acceptable levels, which may be pre-set according to relevant safety standards and/or user defined levels. Here, the temperature controller 106 may be hard wired to the buildings power, or may instead be battery powered such as with a coin cell or similar device, and/or it may even be configured to be powered via solar power.

FIG. 9 is a block diagram of and control box 108 of FIG. 1. The control box 108 includes a microcontroller 902, including a wireless communication coordinator such as ZigBee, for coordinating wireless communications and managing functionality of the system 100. In particular, the microcontroller 902 is configured to receive information from multiple temperature controllers 102 and to provide instructions to associated dampers 104 based on received information. The microcontroller 902 is also configured to provide operating signals to HVAC equipment. Interface connections 906 provide an interface for microcontroller 902 to send and receive data and various suitable inputs and outputs.

The control box 108 further includes an I/O expander 908 to provide additional HVAC output lines if needed. In one example, the I/O expander 908 is a serial to parallel converter. The control box 108 further includes a power source 910. In one example, the power source 910 may be an AC power source. In another example, the power source 910 may include a rechargeable backup battery.

The control box 108 further includes one or more LEDs 912 for assisting a contractor with troubleshooting and configuration. For example, a combination of LEDs 912, using a combination of colors, may provide indications with

respect to whether the wireless network is active, whether the control box **108** is connected to the server **124**, whether the various sensors are functioning properly, the status of the dampers **104**, the status of the temperature controllers **102**, and the status of the HVAC equipment **110**.

The control box **108** further includes a "WiFi join" pushbutton **914** that enables the administrator computing device **122** to connect to the control box **108** and enter a router password. The control box **108** further includes a "Reset" pushbutton **916** that enables users to restart the control box **108** if necessary. The control box **108** further includes a power source button **918** that enables a contractor to select, upon system setup, between an onboard supplied power source **910** and an external alternate power source.

The control box **108** further includes a settings data store **920** for storing various system **100** settings. For example, microcontroller **902** may receive and store in data store **920** settings received from the administrator computing device **122** in connection with the initial setup of the system **100**. The microcontroller **902** may also receive and store in settings data store **920** settings received from the home-owner computing device **120** in connection with user defined preferences. Table 1 lists an example set of parameters that may be received and stored in settings data store **920** as well as a description of the parameter, options for setting the parameter, and example factory default values for the parameters. It should be appreciated that additional suitable parameters may be included as necessary.

TABLE 1

Example System Parameters			
Parameter	Description	Options	Factory Default
System Name	Accepts a string of characters to be used for identifying the control box and its associated control system. Possible string terminators and illegal characters to be defined.	16 characters	Test_System
Server Update Period	Time period between Wi-Fi based server updates, in seconds	10-60 Sec	20
ZigBee Period	Time period of ZigBee communications for all ZigBee devices except ZigBee OA sensor. Impacts battery life and system response time. Time units are seconds.	1-300 Sec	5
ZigBee OAT Period	Time period of ZigBee communications for the outside air temperature sensor (OA sensor). Demo mode sets a period of 5 seconds. Standard operating times are 1, 2, or 3 hours. For app temperature updates, it is suggested to use local weather data rather than the actual OA sensor value, to avoid the perception of a slow sensor.	Demo or 1-3 Hours by integer values	Demo
ZigBee Missed Beacon Retries	Number of additional attempts at contacting a ZigBee mesh node. Impacts power consumption of system.	3-10	3
TC Screen Refresh Period	Time period between temperature controller screen refresh events of the temperature controller, not counting switch interrupt events, in seconds.	10-60 Sec	30
Temperature Display	Determines the temperature display units.	Fahrenheit Celsius	Fahrenheit
TC Data Display Style	Determines the amount and detail of data to be displayed on temperature controller screen. Simple = Temperature, Battery, and HVAC Equipment status only. Detail = Temperature, Battery, HVAC Equipment status, monthly utility bill associated with HVAC setting,.	Simple or Detail	Detail (supports R&D data gathering and troubleshooting)
Damper ZigBee Mode Lock	Forces all dampers into ZigBee Router configuration. This will burn the most battery across the board, but will be useful for the R&D pilot, or to support troubleshooting. ZR Lock = ZigBee Router Functionality Locked ON, Automatic = ZigBee router or ZigBee End Device functionality, depending on scavenging strength and power budget.	ZR Lock or Automatic	ZR Lock (for R&D uses)
Priority Mode	Allows specific mode to interrupt active cycle. Priority options include: Automatic, Heating, Cooling, or Zone Weight Priority. Details to found in definitions section to follow.	Automatic Zone Weight Heating Cooling	Automatic
Zone 1 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 2 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 3 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 4 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 5 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 6 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 7 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 8 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 9 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 10 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 11 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone 12 Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Zone X_{1-i} (i = 99) Weight	Follow the Zone Weight Calculation (below).	10-90%, Δ5%	50%
Minimum On Stage Threshold	Minimum Zone Weight Required to initiate a Heating/Cooling or Fan call to the HVAC Equipment	0-90%, 5% increments	25%

TABLE 1-continued

Example System Parameters

Parameter	Description	Options	Factory Default
A.H. Stage-Up Threshold	CFM Stage-up threshold, Y2 output to Air Handler or W2 to FF Furnace engaged when threshold % is reached. Set the percentage of ductwork you would want to be open before the control board will send a Y2 signal to the air handler to increase CFM or W2 signal to furnace to increase output capacity and CFM.	30-100%, 5% increments	50%
Heat Stage Threshold	Min leaving air temperature required for comfort at 30 degrees outside air temperature. This set point resets by ½ degree for every 1 degree change in outside air temperature. Sets the minimum supply air temperature in the heating mode. At the factory default the control board will maintain a 100 degrees F supply air temperature at 30 degrees F. outdoor temperature. The supply air temperature will raise or lower ½ degree F. for every 1 degree F. change in outdoor air temperature.	80-130 degrees F., 1 degree increments	100 degrees F.
Cool Stage Threshold	Max cooling supply air temp, Y2 is energized if this leaving air temperature is not reached with Y1 output. Sets the maximum supply air temperature allowable before bringing on second stage cooling. Does not reset with the outside air temperature sensor.	20-60 degrees F., 1 degree increments	55 degrees F.
Balance Point - outside air temperature sensor	Heat pump operates above BP set point and FF furnace operates below set-point. Set the outdoor temperature at which you want to lock the heat pump out and have the fossil fuel back up to take over on a call for heat. This setting is overridden by the "Heat Stage Threshold" function.	0-50 degrees F., 1 degree increments or "Lock in Backup Heat" for non-heat pump applications	30 degrees F.
Resistance Lockout - outside air temperature sensor	Aux Heat (Electric Resistance Heat) will be locked out when the outside air temperature exceeds this setting. Set the outdoor temperature at which you want to lock out the electric resistance heat.	0-40 degrees F., or "Lock in Aux" to allow electric aux heat staging regardless of outside air temperature	30 degrees F.
H.P. leaving air temperature Htg. Limit	High limit of heat pump leaving air temperature. Set the maximum allowable supply air temperature in heat pump mode.	100-125 degrees F., 1 degree F. steps	120 degree F.
Cooling leaving air temperature Low Temp	Cooling leaving air temperature low limit. Set the minimum supply air temperature in the cooling cycle to prevent the coil from freezing.	34-46 degrees F., 1 degree F. steps	42 degrees F.
Type of Backup Heat	Specify type of Aux "Backup" heat. Select the type of heat that will be initiated when the heat pump can no longer maintain the setting of te heat stage threshold.	Electric or Fossil Fuel	Electric
Humidification	Required Averaged Humidify throughout conditioned area	0-75%	35%
Backup Controls Fan	G output for fossil fuel heat operation True = "W", False = "W", "G". Select true if the backup heat source controls the fan internally or false if the control box needs to initiate the fan.	True or False	True
Dehumidifier Call Voltage	Required voltage to energize a dehumidification call. (Note: Leave setting at 24 V when not used.) Set to the dehumidification control voltage output on the dehumidistat control, Y.	0 Volt or 24 Volt	24 Volt
Secondary Purge Time	End-of-cycle purge time to diffuse residual heating or cooling. Set the amount of time in seconds to run the pump after a cycle to open all dampers. Typically 5 seconds per damper.	0-180 seconds, 10 second increments	60 Seconds
Dehumidification Cycle Time	Dehumidification "On Cycle" time limit to proven over-cooling of space once cooling set-points are reached (off cycle is fixed at 10 minutes). Set the maximum "ON" time for dehumidification cycle to prevent overcooling of the space. The "OFF" cycle is set at a fixed time of 10 minutes.	5-15 minutes, 5 minute increments	10 minutes
Cooling Low Ambient Lock-Out	Minimum outside air temperature that mechanical cooling is allowed to operate (locks out Y output). Set the outdoor temperature at which the cooling will no longer come on.	20-60, 1 degree F. increments	35
Rev Valve Energized	Heat pump rev valve energize in heating or cooling (Zone 1 HP stat always calls "O" for clg call). Set the mode in which the reversing valve is energized. Note: If the heat pump thermostat has a setting for	Cooling or Heating	Cooling

TABLE 1-continued

	Example System Parameters		
Parameter	Description	Options	Factory Default
	reversing valve in the configuration mode, set the thermostat to energize the reversing valve in cooling.		
Use Balance Point for Electric	Allow Balance Point to be used on all electric system. True heat pump will shut down when ODT is below Balance Point setting.	True or False	False
Demo Mode Enable	Demo mode speeds up all HVAC timing sequences by a factor of 12. Used for demonstrations and for initial system commissioning. ZigBee and Wi-Fi time bases are unaffected and remain set by the parameter values.	True or False	False
Language Selection	Permits user to select language.	English, Spanish, French, Chinese, Japanese, Korean, German, etc.	English

It should be appreciated that the control box **108** may include additional components as well, such as solenoids, relays, and a power supply for providing power and/or control air to the various system HVAC elements. For example, relays may be active in the control box **108** to switch electrical power to the HVAC elements. As another example, to provide air from an air handling unit or pump to one of the air dampers **104**, the microcontroller **902** activates (via an activation signal) a solenoid to switch air to an air damper **104**.

In accordance with one embodiment of the present disclosure, the control box **108** may be accessed by an operator to aid the operator in manually selecting setting options. Such manual selecting includes the steps of powering up the control box **108**, displaying a first set of options, selecting at least one of the options from the first set of options, displaying a second set of options, and selecting at least one of the options from the second set of options. The process of displaying a next set of options and selecting from the next set of options may continue until all available selections are made. Also, the homeowner computing device **120** and the administrator computing device **122** may function as an input/output indicator by displaying each thermostat call and the service currently being provided in accordance with an embodiment of the present invention. In one example, the administrator computing device **122** and the homeowner computing device **120** may be used to access the control box **108** and select such settings options.

In one example, control box **108** may further include a USB (universal serial bus) port. The USB port allows a wireless communications device, for example, a tablet computer, to interface to the control box **108**. In accordance with an embodiment of the present invention, the control box **108** stores a history of operational data (a data log) which may be read out by a computing device via the USB port. Also, in accordance with an embodiment of the present invention, the USB port may be used to allow the control box **108** to interface with suitable home automation equipment (e.g., a home automation device). The control box **108** is designed with suitable "hooks" or APIs for integration with home automation packages. Data that may be output via the USB port to a home automation package include the last five events, the current damper states, the current service being provided, the current LAT, the current OA sensor, and any current thermostat or sensor requests. The home automation equipment may include a separate device with software that takes the data provided by the control box **108** and reports

the data to a remote user, email, or a web-based interface, for example. The user may have the capability to respond to the report in a similar manner in order to, for example, change the temperature in the home or turn off part of the HVAC system. The interface between the control box **108** and the home automation equipment may be wireless in accordance with various embodiments of the present invention.

Configuration and operation of system **100** may be further appreciated in view of the homeowner computing device **120** and the administrator computing device **122**. FIG. **10** illustrates a block diagram of an example homeowner computing device **120** for enabling a homeowner or other user to interface with system **100**. Homeowner computing device **120** includes a sign-in module **1002** for enabling a homeowner to sign in to an account. The sign-in module **1002** also enables a homeowner to sign up for a new account if it's the homeowner's first time using the homeowner computing device **120**. As part of the sign-up process, the sign-in module **1002** requires the homeowner to select a wireless home network for accessing the control box **108**. It should be appreciated that, although references are made herein with respect to a homeowner, any suitable user with proper access credentials may interface with homeowner computing device **120**.

The homeowner computing device **120** further includes a dashboard module **1004**. The dashboard module **1004** provides the homeowner with a centralized view of, and access to, the HVAC system for a home. For example, the dashboard module **1004** communicates to the homeowner the current temperature of the home. In one example, the dashboard module **1004** accesses weather through a third party service such as Google or Yahoo. The dashboard module **1004** further communicates to the homeowner a summary of different defined zones of the home. For example, the dashboard module **1004** displays, for each zone, the temperature in that particular zone, whether the zone is currently being heated, cooled, or neither, and whether the zone is locked or unlocked indicating whether the temperature of the zone can be adjusted. The dashboard module **1004** further enables a homeowner to select a specific zone and access more detailed information about the selected zone. The dashboard module **1004** further enables a homeowner to review the currently set heating and cooling schedule and to select a different defined schedule. The dashboard module **1004** further enables the homeowner to select a defined schedule in order to view more details or to

make edits. The dashboard module **1004** also provides a homeowner with an option of creating a new schedule.

The homeowner computing device **120** further includes a zone module **1006**. In response to a homeowner selecting a zone via the dashboard module **1004**, the zone module **1006** communicates an overview of the selected zone to the homeowner. For example, the zone module **1006** displays the temperature of the zone as well as heat and cool set points. In one example, both the heat and cool set points are displayed while the zone mode is set to auto, only the heating set point is displayed when the zone mode is set to heat, and the only the cool set point is displayed when the zone mode is set to cool. In one example, the zone module **1006** is further configured to display a humidity level for a selected zone. In one example, the zone module **1006** is further configured to display a status of the zone. In one example, the zone module **1006** is further configured to display the assigned schedule for the zone. For example, the zone module **1006** may be configured to display "30 minutes until cooling down to 65 F" if the zone is schedule to be cooled down to a temperature of 65 F in 30 minutes. The zone module **1006** also enables a homeowner to return to an overview of all of the zones provided by dashboard module **1004**.

In one example, the zone module **1006** enables a home-owner to quickly switch to viewing information about another zone without accessing the dashboard module **1004**. For example, the zone module **1006** may enable the homeowner to swipe to the left or right on a touch screen of the homeowner computing device **120** in order to change zone views.

It should be appreciated that "communicating" as used herein may include transmitting data to a display of the homeowner computing device **120** for a homeowner to view. In addition, "communicating" may also include other suit-able forms or conveying information, such as audibly, by storing and communicating data electronically, and so on.

In one example, the zone module **1006** enables the homeowner to initiate a "zone hold" which occurs when a homeowner changes the set point to anything other than a set point in the schedule. When a hold occurs, the zone module **1006** changes the status of a zone to default hold. In one example, the default hold is a hold that lasts until the next scheduled profile is assigned. In one example, the zone module **1006** enables a homeowner to change the hold option. For example, the zone module **1006** may enable the homeowner to select one of several hold options including: "hold until next schedule," "hold for an amount of time," where the time is configurable, or "hold indefinitely." In addition, the zone module **1006** may enable the homeowner to cancel the hold and revert back to the selected schedule.

The homeowner computing device **120** further includes a scheduling module **1008** configured to enable a homeowner to select a schedule to run for a zone. The scheduling module **1008** may provide one or more predefined schedules for a homeowner to choose from. For example, the scheduling module **1008** may provide a predefined "primary" schedule which may be a seven-day schedule and may be the most commonly selected schedule. The scheduling module **1008** may further provide a predefined "away" schedule for vacations and business trips, for example. The scheduling module **1008** may also provide a predefined "energy savings schedule" which may include parameters designed to main-tain a certain comfort level in a zone while saving energy costs.

The scheduling module **1008** further enables a home-owner to view details about schedules, to edit existing schedules, and to add new schedules. For example, the scheduling module **1008** may enable a homeowner to define specific days associated with a schedule, specific tempera-tures for certain defined times of the day such as "morning", "away," "arrive home," and "sleep." The scheduling module **1008** enables the homeowner to set different schedules for individual zones or to set a single schedule and apply it to all zones.

The homeowner computing device **120** further includes a messaging module **1010**. The messaging module **1010** is configured to communicate various types of messages to a homeowner that may be generated by the system **100**. For example, messaging module **1010** may be configured to receive "information" messages which are for information purposes only and require no action. In some examples, the messaging module **1010** may be configured to alert the end user about up-coming scheduled maintenance and/or appointments regarding the same. Messaging module **1010** may further be configured to receive "warning" messages which may require troubleshooting by the homeowner. The messaging module **1010** may further be configured to receive "error" messages which may require attention by a contractor. The messaging module **1010** may further be configured to receive "energy tip" messages which may inform the homeowner about potential ways to conserve energy. In one example, such "energy tip" messages may be generated by the computer data server **124** based on histori-cal temperature data or other historical data and/or may suggest to the end user an adjustment based on such data (e.g., increase or decrease heating or cooling). The messag-ing module **1010** may further be configured to receive "success" messages indicating a contractor's successful visit or system upgrade. It should be appreciated that the mes-saging module **1010** may be configured to receive other suitable types of messages that may or may not require specific actions by the homeowner or the contractor. For example, messaging module **1010** may be configured to provide current weather information and/or weather forecast information to the end user. In such examples where the messaging module **1010** provides current weather informa-tion and/or weather forecast information to the end user, "energy tips" may be provided to the messaging module **1010** to inform the end user if the weather is changing and/or suggest turning up or down the HVAC equipment **110** based on that information.

In one example, if a message does not require action including contractor assistance, the messaging module **1010** may be configured to provide the homeowner with an option to delete the message after it is read. In one example, if a message does require action including contractor assistance, the messaging module **1010** may be configured to provide the homeowner with an option to contact the contractor. For example, the messaging module **1010** may provide a home-owner with an option of either calling or emailing the contractor. If the homeowner selects the "call" option, the messaging module **1010** may automatically initiate a tele-phone call to the contractor. If the homeowner selects the "email" option, the messaging module **1010** may open an email template from the homeowner's default email appli-cation and prepopulate the template with information pre-sented in the received message including, for example, a diagnostics report, a description of any detected failures or issues, and/or a parts list of any parts needed to address or fix the issue. In one example, the messaging module **1010** may prepopulate the email address with the appropriate email address of a contractor associated with the homeown-er's account. In one example, the messaging module **1010**

may be configured to automatically contact the contractor, either by email or a telephone call, when a message that requires action including contractor assistance is generated. Thus, a self-diagnostic feature may be provided that alerts the contractor that something is wrong with the system 100, and lets the contractor know the parts needed to fix the problem and may also provide the contractor with instructions for solving the problem as well. In some examples, the homeowner may order replacement parts or other products or services via the homeowner computing device 120, for example, the messaging module 1010. In some examples, the system 100 may be configured to alert the contractor of a predicted failure and order the necessary parts without the user's input.

The homeowner computing device 120 further includes a settings module 1012 for enabling a homeowner to access and adjust various suitable settings. For example, the settings module 1012 may enable a homeowner to add or delete other users and to grant them access to one or more zones within a location or to all zones within a specific location. In one example the settings module 1012 may enable a homeowner to view and edit contractor information. It should be appreciated that the settings module 1012 may further be configured to enable a homeowner to modify other suitable settings, including, for example, zone names, WiFi configuration, display preferences, access credentials and levels of users, and so on.

The system 100 may also include energy conservation functions whereby the end user is rewarded for conserving energy. The "energy tips" may advise the end user to adjust operation of the HVAC equipment 110 based on historical data. In some examples, these "energy tips" may be tied to energy supplier promotions and/or rebates. For example, an end-user's energy supplier may be notified that the end-user is conserving energy by following the "energy tips" such that the end user is eligible for promotions, rebates, reduced rates, etc. The "energy tips" may also provide the end user the option of whether to let the energy supplier remotely control the system 100 and/or the HVAC equipment 110, for which the energy supplier may reward the end-user with energy discounts or rebates. For example, energy suppliers may offer rebates or discounts to end-users permit the energy supplier to control heating and cooling in the building (or one or more zones thereof) during peak power usage times.

FIG. 11 illustrates a block diagram of an example administrator computing device 122 for enabling a contractor, an energy supplier, or other systems administrator to interface with system 100. Administrator computing device 122 includes a sign-in module 1102 configured to receive login credentials from a contractor and to grant access to the system 100 upon successfully validating the received credentials. If the contractor is accessing a system 100 for the first time, the sign-in module 1102 requires provisioning of the system 100. For example, the sign-in module 1102 requires the contractor to select from a list of detected control boxes 108 and to provide an identifier such as serial number, or other suitable information, to ensure that the contractor is accessing the correct control box 108. In one example, the sign-in module 1102 may require the contractor to perform some interaction with the control box 108, such as to push a button or observe a flashing light in order to further ensure that the contractor is accessing the correct control box 1108.

The administrator computing device 122 further includes a dashboard module 1104 for providing information about the system 100 that the contractor can use for maintenance, monitoring, and troubleshooting purposes. The dashboard

module 1104 may also be configured to permit the contractor or energy supplier to control the system 100 and/or the HVAC equipment 110 for example, for energy conservation purposes.

If a contractor is accessing a control box 108 for the first time, a setup module 1106 enables a contractor to set up a system by defining hardware of the system 100 and associating the hardware with different zones. For example, the setup module 1106 may enable a contractor to drag and drop hardware, such as dampers and temperature controllers, from a list of available unassigned hardware and to associate the hardware with specific zones. Thus, zones can be defined in a variety of ways including a single room of a home, multiple rooms, a portion of a room, and so on. In one example, the setup module 1106 enables a contractor to initiate an LED indicator of a selected hardware to flash in order to ensure that the correct hardware is being assigned to a specific zone. In one example, the setup module 1106 enables a contractor to define new zones, edit zones, or delete zones.

The administrator computing device 122 further includes messaging module 1108 configured to enable a contractor to draft and communicate messages to a homeowner about the status of the system 100. In one example, the messaging module 1108 may include one or more predefined messages that the contractor can select from and send to the homeowner. In some examples, the messaging module 1108 may be configured to alert the contractor and/or energy supplier about up-coming scheduled maintenance and/or appointments regarding the same.

In some examples, the system 100 is configured to predict and address failures before they occur. For example, the system 100 may be configured to sense changes in operation of various components of the system 100 and/or the HVAC equipment 110 or count cycles to determine the likelihood of something failing. Upon determination that failure is likely, the system 100 may be configured to order a replacement part and/or schedule preventative maintenance appointment. For example, if it is known that a certain component of the damper 104 is susceptible to failure after a certain number of cycles or after being in operation a certain amount of time (e.g., that the damper motor or any other part begins to weaken after a certain number of cycles (i.e., X cycles)), then the system 100 may be configured to make a recommendation to the installer that this certain component should be addressed (e.g., recommend to the installer that the motor or other part should be replaced) to prevent a future failure before the components actually breaks and causes an issue.

FIG. 12 is a schematic diagram of an example computer 1200 for implementing the example homeowner computing device 120 and the administrator computing device 122 of FIG. 1. The example computer 1200 is intended to represent various forms of digital computers, including laptops, desktops, handheld computers, tablet computers, smartphones, servers, and other similar types of computing devices. Computer 1200 includes a processor 1202, memory 1204, a storage device 1206, and a communication port 1208, operably connected by an interface 1222 via a bus 1210.

Processor 1202 processes instructions, via memory 1204, for execution within computer 800. In an example embodiment, multiple processors along with multiple memories may be used.

Memory 1204 may be volatile memory or non-volatile memory. Memory 1204 may be a computer-readable medium, such as a magnetic disk or optical disk. Storage device 1206 may be a computer-readable medium, such as floppy disk devices, a hard disk device, optical disk device,

a tape device, a flash memory, phase change memory, or other similar solid state memory device, or an array of devices, including devices in a storage area network of other configurations. A computer program product can be tangibly embodied in a computer readable medium such as memory **1204** or storage device **1206**.

Computer **1200** can be coupled to one or more input and output devices such as a display **1214**, a printer **1216**, a scanner **1218**, and a mouse **1220**.

To the extent that the term "includes" or "including" is used in the specification or the claims, it is intended to be inclusive in a manner similar to the term "comprising" as that term is interpreted when employed as a transitional word in a claim. Furthermore, to the extent that the term "or" is employed (e.g., A or B) it is intended to mean "A or B or both." When the applicants intend to indicate "only A or B but not both" then the term "only A or B but not both" will be employed. Thus, use of the term "or" herein is the inclusive, and not the exclusive use. See, Bryan A. Garner, A Dictionary of Modern Legal Usage 624 (2d. Ed. 1995). Also, to the extent that the terms "in" or "into" are used in the specification or the claims, it is intended to additionally mean "on" or "onto." Furthermore, to the extent the term "connect" is used in the specification or claims, it is intended to mean not only "directly connected to," but also "indirectly connected to" such as connected through another component or components.

While the claimed subject matter of the present application has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the claimed subject matter. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the claimed subject matter without departing from its scope. For example, any system **100** component described herein could be of either wired or wireless connection, according to various embodiment. Therefore, it is intended that the claimed subject matter not be limited to the particular embodiment disclosed, but that the claimed subject matter will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A damper for an HVAC system configured to distribute airflow through at least one air duct, the damper comprising:
   a rail assembly for providing support to the damper and securing and sealing the damper on the air duct;
   a damper blade assembly for regulating the amount of airflow passing through the air duct, the damper blade assembly having blade that is movable between an open position and a closed position;
   a damper module configured to control an orientation of the blade between the open position and the closed position;
   a scavenger assembly removably attached to the rail assembly and configured to harvest energy from airflow passing by the damper inside the air duct, wherein the

scavenger assembly, when detached from the rail assembly, may be positioned at a first location within the air duct that is spaced apart from a second location where the rail assembly is installed on the air duct; and
   a scavenger module configured to store power generated from energy harvested by the scavenger assembly and to supply power to the damper module for positioning the blade.

2. The damper of claim **1**, wherein the damper operates in a scavenger mode using only power generated by the scavenger assembly where airflow is greater than or equal to a predefined maximum rate.

3. The damper of claim **2**, further comprising a supplemental power source configured to supply power to the damper where airflow is less than the predefined maximum rate.

4. The damper of claim **3**, wherein the damper operates in a supplemental power mode using power supplied only by the supplemental power source where air flow is less than or equal to a predefined minimum rate, wherein the predefined minimum rate is less than the predefined maximum rate.

5. The damper of claim **4**, wherein the damper operates in a hybrid power mode using power supplied by both the scavenger assembly and the supplemental power source where airflow is less than the predefined maximum rate and greater than the predefined minimum rate.

6. The damper of claim **3**, wherein the supplemental power source is selected from the group consisting of a rechargeable battery and an external power source hardwired to the damper, and combinations of the same.

7. The damper of claim **1**, wherein the scavenger assembly includes an impeller that rotates as airflow passes by, and wherein the scavenger module is configured to translate the rotation of the impeller into power.

8. The damper of claim **7**, wherein the impeller is configured as an anemometer for measuring velocity of airflow.

9. The damper of claim **8**, wherein the damper determines whether to operate using a supplemental source of power based on feedback indicative of velocity of airflow.

10. The damper of claim **8**, wherein the damper module adjusts orientation of the blade based on feedback indicative of velocity of airflow.

11. The damper of claim **7**, wherein the impeller does not boost airflow through the air duct.

12. The damper of claim **1**, wherein the rail assembly is secured over a removed portion of the air duct.

13. The damper of claim **1**, wherein the damper module includes a sensor configured to measure the rate at which the damper module actuates the blade.

14. The damper of claim **13**, wherein the damper module includes a controller that is in communication with the sensor and is configured to determine position of the blade from feedback received from the sensor.

15. The damper of claim **13**, wherein the sensor is at least one Hall Effect sensor.

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